Retrofitting with heat pumps in buildings

Survey Report
HPC - AR9

IEA
OECD
heat pump centre

Retrofitting with heat pumps in buildings

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July 2001
Survey Report no. HPC-AR9

Published by

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Production

IEA Heat Pump Centre, Sittard, the Netherlands

ISBN

90-73741-41-6

The IEA Heat Pump Centre

The IEA Heat Pump Centre (HPC) is the focal point of the Implementing Agreement on Heat Pumping Technologies of the International Energy Agency (IEA), also called the IEA Heat Pump Programme.

The IEA was founded in 1974 as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. Activities are directed towards the IEA Member countries' collective energy policy objectives of energy security, economic and social development, and environmental protection.

One important activity undertaken in pursuit of these goals is a programme to facilitate co-operation to develop new and improved energy technologies and introduce them into the market. Activities are set up under Implementing Agreements which provide the legal mechanism for establishing the commitments of Participants and the management structure to guide the activity. There are 40 currently active Implementing Agreements, encompassing activities relating to fossil fuels, renewable energy, efficient energy end-use, fusion power and information dissemination. This publication concerns the Implementing Agreement on Heat Pumping Technologies.

The member countries of the HPC form a network for exchanging information on heat pump technology. By increasing awareness and understanding worldwide, the HPC aims to accelerate the implementation of heat pump technology as a means to reduce energy consumption and thereby to limit harmful environmental effects. HPC tasks include:

- Collecting, analysing and disseminating heat-pump-related technical, market, regulatory, and environmental information;
- Fostering international co-operation in research and development; and
- Facilitating contacts and information exchange among those involved in the research, development, design, manufacture, regulation, marketing, and application of heat pumps.

Foreword

The market potential of heat pumps for retrofit is substantially larger than for heat pumps in new buildings. Yet this potential is far from being realised in many countries. An important reason for this situation is the high distribution temperatures required in existing heating installations.

To achieve a worldwide reduction of CO_2 emissions, increased deployment of heat pumps for retrofitting is essential. In recent years, the market for heat pumps in new buildings has been growing in some countries. Attention to the retrofit market is also increasing, in the wake of the market for heat pumps in new buildings.

Several initiatives are being undertaken to remove market barriers to an increased deployment of heat pumps in retrofit applications:

- Manufacturers are developing products tailored to the retrofit market;
- Improved building standards and materials create opportunities to reduce the heat demand and the heat distribution temperature in existing buildings; and
- Modern controls allow designs that are tailored to existing heating systems.

The Heat Pump Centre member countries agreed that a survey of the market for retrofit heat pumps was timely, and would assist further market penetration. This report is the result of that survey. It contains useful information for architects and planners, as well as for policy-makers and utilities, which will play an important role in increasing the application of heat pumps.

We believe that this report provides relevant information and knowledge to promote the use of heat pumps in retrofit applications, and therewith contributes to mitigate global warming.

IEA Heat Pump Centre
June 2001

Acknowledgements

This report is the result of the HPC Tailored Collaborated Programme – Project TCP 99/2. It has been carried out by InterConsult Group ASA, Norway, in close co-operation with SINTEF Energy Research and the IEA Heat Pump Centre.

From the InterConsult Group ASA, we would like to thank in particular Ms Anne Gundersen Haugland and Mr Ziad Nahra for their contributions to the report.

Thanks are also due to the following persons for their contributions:

- Kisuke Yamazaki, HPTCJ, Japan, who provided input to the questionnaire at the start of the project;
- Hermann Halozan, University of Technology, Graz, Austria, who carried out a detailed review of the report;
- Martin Zogg, BFE Forschungsprogramm UAW, Switzerland, who contributed the chapter on cycles adapted for retrofit application; and
- Jørn Stene and Rune Aarlien, SINTEF Energy Research, Norway, who were very helpful throughout the work, and gave comments and advice at the different project stages.

Thanks also go to the International Institute of Refrigeration (IIR), who have reviewed the report in collaboration with Hermann Halozan, Chairman of Commission E2.

Contents

Glossary and abbreviations

AHP	Absorption heat pump.
Carnot cycle	The ideal thermal cycle.
COP	Coefficient of performance (of a heat pump, heat exchanger or other thermal device or system).
CFC	Chlorofluorocarbon (once the most common category of refrigerants, but now banned because of their impact on ozone depletion).
CHP	Combined heat and power.
CO_2	Carbon dioxide (the principal greenhouse gas).
DAHP	Diffusion/absorption heat pump.
DHW	Domestic hot water.
GHP	Geothermal heat pump.
GWP	Global warming potential.
HCFC	Hydrochlorofluorocarbon (the approved category of refrigerants which is replacing CFCs and HFCs).
HE	Heat exchanger.
HFC	Hydrofluorocarbon (category of refrigerants which first replaced CFCs, but is now also being phased out).
HFE	Hydrofluoroethers.
HHV	Higher heating value (of a fuel)
HP	Heat pump.
Hydronic	A type of heat distribution system employing water as the transfer medium.
Kyoto Protocol	The 1997 international agreement to limit the emission of greenhouse gases. The ratification of the protocol was highly uncertain at the time of writing.
LHV	Lower heating value (of a fuel).
Montreal Protocol	An international agreement to eliminate the use of refrigerants which contribute to ozone depletion.
ODP	Ozone depletion potential.
PAC	Packaged air conditioner.
PER	Primary energy ratio (of a heat pump).
R-12, R- …	The initial R denotes a standard refrigerant.
RAC	Room air conditioner.
SPF	Seasonal performance factor.
SRHP	Swiss retrofit heat pump – subject of a competition by the Swiss Federal Office of Energy (SFOE).
TEWI	Total equivalent warming impact.

Part 1 – Executive Summary

Executive Summary

I Introduction

The potential market for heat pumps for retrofitting in existing heating systems is substantially larger than for application in new buildings. However, in most countries, this potential is far from being realised. This report provides an overview of what is being done to overcome the technical market barriers, in particular to find solutions for the high distribution temperatures which are often required for existing hydronic heat distribution systems.

Retrofitting is a means of rectifying existing building deficiencies, improving the standard of a building and, sometimes, making it suitable for alternative uses. It reflects the need to maintain and preserve the building for a longer period of time than the life of its technical equipment. Building retrofit often includes replacing the heating system. Heating systems may also be retrofitted without changing the building itself.

Retrofitting of heating systems with heat pumps has its own specific problems, of which the high distribution temperature used in existing hydronic distribution systems is the most prominent. This report provides possible solutions to these problems. Cooling is not considered in detail. The geographical focus is on northern, western and central Europe, as the challenges with high-temperature heat distribution are typical for these regions.

II The market

The potential market for retrofit heat pumps is about three times larger than the market for heat pumps in new buildings. The new building construction rate is about 2% of the existing building stock annually in most countries. If a heating (and cooling) system needs to be replaced after 15 – 20 years of use, then 5 – 6% of the existing building stock is confronted with the need for a retrofit every year.

However, in most countries the real market for retrofit heat pumps is substantially smaller than the market for their applications in new buildings. Even in the USA, only about 50% of unitary heat pump shipments replace existing heating and cooling systems (see Section 3.1.2). In the USA, heat distribution is by ducted air systems in most existing buildings, and consequently the barrier for incorporating the heat pump in the existing distribution system is expected to be smaller than in most northern and central European countries. In Switzerland, only about 20% of the heat pump market (<20 kW) is for retrofit. This corresponds to 3% of the market for replacing/retrofitting existing heating systems. In Germany, retrofit heat pumps are estimated to account for around 25% of the market.

In Norway and Japan, the markets for heat pumps for retrofit are better developed. In Norway, approximately 50% of the heat pump installations are ductless air-to-air split units. Most of them are installed for replacing room heaters in existing single-family houses, which previously were heated with electric resistance heaters. In Japan, the replacement market is dominant, and heating and cooling heat pumps are replaced every 10 – 11 years. In 1999, the replacement market for heat-pump-type room air conditioners (RACs) was 5.4 million units, which is 88% of the total heat-pump-type RAC market. The 1999 replacement market for heat-pump-type packaged air conditioners (PACs) was 440 thousand units, which was 70% of total heat-pump-type PAC shipments. In the UK, the replacement market is strong in commercial buildings, estimated at 67% in 1996.

An IEA Heat Pump Programme analysis in 1999 revealed that heat pumps can cut global CO_2 emissions by more than 6% [1, 2]. This potential will be realised when 30% of the buildings are heated with state-of-the-art heat pumps, which save at least 30% CO_2 emissions compared to conventional heating methods. This message is still valid today, but to realise the potential, the retrofit heat pump market must be increased.

III Market barriers

There are several barriers obstructing the market for retrofit heat pumps, including both technical restrictions and economical factors. The main barriers are:

- High distribution temperatures in existing systems. The traditional hydronic heating systems require high supply temperatures in the range of 90 – 70ºC. This is much higher than the high-temperature limit of most heat pumps, which is around 55ºC, depending on the type of working fluid.

- As a result of the high distribution temperatures, the heat pump system must operate with high temperature lifts between the heat source and the heat sink. This means a lower COP for the heat pump system, and a higher compressor discharge gas temperature. This may result in a shorter working life for the heat pump, and a greater risk of compressor failure. The low COP is aggravated by the fact that outside air is the most obvious heat source, as it may be difficult to install a ground-source heat exchanger or well system near an existing house or building.

- Heat pumps for retrofit tend to be less cost-effective than heat pump installations in new buildings because the higher temperature lifts result in lower COPs. The retrofit heat pump may also require extra investment for a machinery room, piping, automation and electric installations compared with installations in new buildings.

- Heat pumps for retrofit often meet restrictions in the space available for the new installation. Heat storage tanks are often impossible, and the installation of a ground-source heat exchanger or a ground well may be difficult.

IV Possible solutions

IVa Reducing the required supply temperature

There are several methods for reducing the distribution temperature of an existing heat distribution system. Old hydronic systems are often designed for higher heating capacities than the actual design heat demands. In that case, the distribution temperatures may be reduced below the original design values. The distribution temperatures may be reduced further by reducing the specific heat demand (W/m2) by improved insulation of the walls, installation of new windows with lower u-values, etc. Changing the strategy of night set-backs will lead to reduced heat demand in the morning, and lower distribution temperatures will be sufficient to maintain the required room temperature. However, it should be ensured that the heat pump in combination with the new control method really saves energy.

Replacing the existing heat distribution system with a new low-temperature system is another measure to improve the operating conditions. A good technical solution is to replace the existing high-temperature hydronic system with e.g. a new floor heating system, but this may be expensive. Another approach is to install additional heat transfer surface in specific rooms by means of larger radiators or more efficient heat exchangers.

Another possibility is bivalent operation, in which the heat pump covers the base load and an auxiliary heating system the peak load. This reduces the overall system efficiency, but makes it possible to operate with a supply temperature of e.g. 70ºC at design conditions.

IVb Ductless air-to-air systems

Ductless air-to-air heat pumps are attractive when there is no heat distribution system available. In Japan, the market is dominated by these systems, which are successful for retrofit as well. Their performance is similar in retrofit applications and in new buildings. However, most units on the market are not optimised for heating-only in cold climates.

IVc Working fluids for higher temperatures

The highest recommended temperature in single-stage, small- and medium-size heat pump systems that use HFC refrigerants is 60 – 65°C. With the use of larger centrifugal R-134a compressors in two-stage heat pump installations, the temperature limit may be increased. For small- and medium-size heat pump systems, however, higher temperature limits may be achieved by using natural working fluids such as hydrocarbons, ammonia and carbon dioxide.

The hydrocarbons butane and iso-butane, and mixtures of hydrocarbons may be used up to 100°C. They are therefore interesting for retrofit applications. The rather high pressures on the condenser side of ammonia systems limit their application in heat pumps for higher temperatures when normal 25 bar equipment is used. Carbon dioxide (CO_2) can be used as a working fluid in a trans-critical process.

IVd Cycles and controls

There are some technical possibilities to improve the chances for retrofitting with heat pumps, e.g. by using two-stage compression, compression with saturated vapour injection, and trans-critical cycles with hydrofluoroethers. Studies of such systems have been carried out in Germany and Switzerland.

IVe Absorption systems

Thermally-activated heat pumps have the advantage of a high-temperature driving energy. Gas-fired absorption heat pumps are therefore particularly suited for the retrofit market. The Dutch company Nefit Buderus has developed a 4 kW heating diffusion absorption heat pump for the retrofit market. Field tests have been completed in the Netherlands and Germany.

Another gas-fired absorption heat pump for the retrofit market was developed by Heliotherm in Austria. The 18 kW heating heat pump can be used with various heat sources. A prototype has been tested, and a field test is planned in 2001.

V Other factors

A high quality of system design and installation, and a focus on cost-effective solutions are at least as crucial in the retrofit market as in the market for new building construction. Concerning economy of the installation, for retrofit long operating hours at base load are very important. From that viewpoint, integrated systems for space heating and hot water production are potential retrofit applications. Health and care institutions with a day-round, high demand for space heating are also applications where successful retrofitting with heat pumps can be expected.

VI Conclusions

The market for retrofit heat pumps could be three times the market for heat pumps in new buildings if there were no barriers for retrofitting with heat pumps. These barriers are mainly technical, and especially related to high distribution temperatures in hydronic heat distribution systems, which reduce the efficiency and the economy of the heat pump installation. These barriers may be removed by reducing the distribution temperatures, and by introducing specially-designed heat pumps.

Part 2 – Survey

1 Introduction

1.1 Background

The new building construction rate per year is on average between 2 – 3% of the total building stock [1]. But 5 – 6% of the building owners are annually confronted with the necessity to renovate their heating system. Therefore, the market potential of heat pumps for retrofitting existing heating systems is much higher than for installations in new buildings.

State-of-the-art technology, and tradition with regard to heating systems, differ from one country to another. The use of heat pumps in general also varies quite widely because of different energy situations, and government/utility incentives.

A number of factors affect the heating and cooling demand for buildings. These factors are generally climatic conditions, the construction of the building including its size, degree of insulation and standard of ventilation, the use of the building with regard to internal heat gains and the desired comfort level. The development of the residential building sector in recent years has not always contributed to reduction in energy consumption, due to several demands such as increased floor area per person, higher comfort demands and increase in use of domestic hot water (DHW). In commercial buildings there is a trend towards greater cooling, due to increased internal heat gains and higher comfort demands.

The commitments of the Kyoto Protocol[1] require our action to achieve a reduction in CO_2 emissions and thus a reduction in energy consumption. Heat pumps can play an important role to achieve this in buildings. This report investigates the important market for retrofitting existing heating systems with heat pumps.

1.2 Aim

The general aim of the project is to contribute to an increased market share for heat pumps in existing buildings by identifying market impediments and technical possibilities.

1.3 Target audience

The primary target groups for the study are architects, consulting engineers, manufacturers and installers. Secondary target groups are policy-makers and utilities, and others in a position to influence decisions.

[1] Though the ratification of Kyoto was highly uncertain at the time of writing, global action to mitigate global warming will be required one way or another.

1.4 Scope

This survey describes the present situation and the potential for installing heat pumps for retrofit in different countries. The report mainly deals with heat pumps for retrofit in hydronic heating systems.

The survey focuses on heat pumps for space heating and cooling in existing residential buildings. However, heat pump water heaters and heat pumps in small commercial applications are included as well.

The survey covers the following aspects:
- Technology developments and technical barriers;
- Performance and experiences;
- Market status and market impediments; and
- Incentive and promotional programmes, particularly related to retrofit with heat pumps.

1.5 Methodology

The information has been gathered by literature searches, especially from IEA Heat Pump Centre Reports, and from Internet searches.

2 Market potential of heat pumps for retrofit

Heat pumps are competing with conventional and other renewable heating systems, and the decision to install a heat pump system normally requires the fulfilment of one or more of several factors:

- Primary energy savings;
- Environmental advantages;
- Cost-effectiveness; and
- Increased comfort.

In addition, the reputation of heat pump technology as well as the availability of heat pumps in the market will affect the interest in installing heat pumps.

The situation varies considerably from one country to another with regard to these factors, so the potential for installing heat pumps also varies.

2.1 Market status

The three most relevant heat pump market regions are North America, Asia Pacific and Europe. Figure 2.1 shows the share of the world market for comfort heat pump systems (1998).

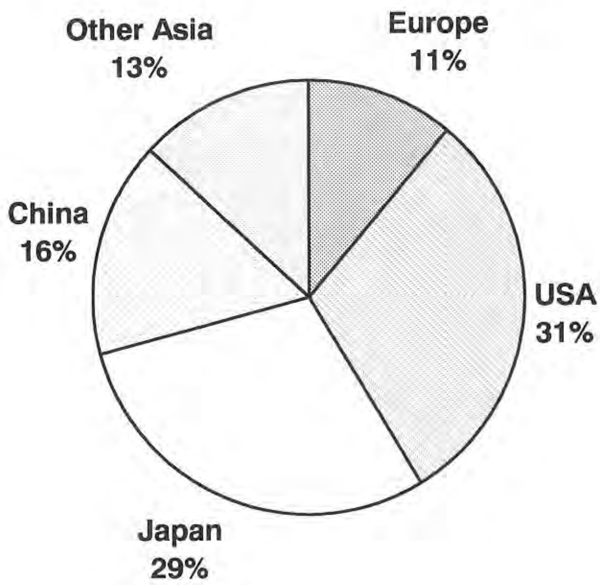

Figure 2.1 *Share of the world market for comfort heat pump systems, per region [3].*

2.1.1 Heat pump market and market trends

North America

North America has a large heat pump market, and the US share amounts to more than 30% of the worldwide market for comfort system, Figure 2.1. In 2000, total sales of air conditioning and heat pump unitary equipment (not including single-room units) were over 6.6 million units. Of these, 1.34 million units were unitary heat pump systems for commercial and residential applications. About 50% of unitary air conditioner and heat pump shipments replace existing heating and cooling systems. The best market growth opportunities are expected to occur in the replacement market [4].

Asia and Oceania

In the Asia Pacific Region, 18.6 million units of room air conditioners/packaged air conditioners were sold in 1999, and this is about half of the world market (38 million units sold in 1999). Japan has a mature heat pump market, with 6.2 million units sold in 1999. China has seen a rapid growth in sales of heat pumps over the past few years, with an estimated 4.5 million units sold in 1999. Also in the other Asian countries, market penetration of room air conditioners/packaged air conditioners is very high, but mainly for cooling-only. The summer electricity shortage leads to increasing demand for absorption and thermal storage systems [3].

In Japan, most heat pump sales are for replacement of existing heating and cooling systems. Heating and cooling heat pumps are replaced every 10 years. In 1999, the replacement market of heat-pump-type room air conditioners (RACs) was 5.4 million units, which was 88% of the total heat-pump-type RAC market. The 1999 replacement market for heat-pump-type packaged air conditioners (PACs) was 440,000 units, which was 70% of total heat-pump-type PAC shipments.

Europe

The European heat pump market is extremely diverse, due to the wide variety of factors that influence the market, e.g. climate, national energy resource situation, energy prices, etc. The space conditioning heat pump market is most significant in regions with a cooling demand. The growing demand for space cooling in residential buildings in the central and northern European market offers new possibilities for heat pumps [5].

The heat pump market, and market trends in some European countries are discussed below:

- **Austria:** During the last five years, heat pump sales have been around 5,000 heating-only units per year, not counting reversible air-to-air units. About 2,000 residences are annually equipped with ground-coupled heat pump systems. Approximately 150,000 heat pump units are currently used in the residential sector. 35,000 are used for space heating purposes and exhaust air heat recovery, and 115,000 are mainly small heat pump water heaters.

- **Germany:** In Baden Württemberg, one of the German states along the Swiss border, the market share of heat pumps is 14 times lower than in the neighbouring country of Switzerland, where one in every three new houses has a heat pump. To stimulate the use of heat pumps in this part of Germany, particularly in existing buildings, a workshop entitled "Application of heat pumps in existing buildings" was organised in July 1999 in Karlsruhe [6]. In Germany, heat pumps for retrofitting existing heating systems are estimated to be 25% of the heat pump market.

- **The Netherlands:** The overall heat pump market is growing steadily, but mainly in the commercial building sector. The installed stock increased by more than 50% in the period 1994 – 99, and stands at a total of 29,500. Of these, only 5,600 are in residences. The number of heat pumps installed in residences was 842 in 1999. Retrofitting also occurs mainly in the commercial sector.

- **Norway:** The total sales of heat pumps in Norway was around 2,600 units in 1999, according to NOVAP (Norwegian Heat Pump Association). More than 50% of the heat pumps are split-type air-to-air systems, and most of these are installed in existing homes (for replacement of direct electric heating). The total heat pump stock at the beginning of 2001 was about 27,000 units.

- **Sweden:** In Sweden more than 20,000 heat pump units were sold in 1999 according to SVEP (the Swedish Heat Pump Association). The total heat pump stock was approximately 300,000 units. 64% of new installations are ground-source heat pumps, and installations in rock dominate the sector. 30% of the market is exhaust-air-source systems, primarily installed in new houses.

- **Switzerland:** The heat pump market in Switzerland has grown significantly since FWS (the Swiss Heat Pump Promotion Group) was established in 1993. The annual heat pump installation rate for 1999 was 7,000, compared to 3,000 in 1993. This success is a result of the broad support by installers and utilities as well as federal and regional governments. Only about 20% of the heat pump market (<20 kW) is for retrofit.

  Over the next few years, there will be no more federal subsidies, and most regional subsidies are expected to be reduced or phased out.

- **United Kingdom:** In the UK, the number of new installations in commercial buildings had grown to almost 60,000 per year in 1996. This is 96% of all the heat pumps installations in buildings. Around 80% of these installations are of the water-loop type. The residential market is negligible.

2.2 Government and utility policy

Heat pump promotion plays an important role in clearing the path for a wider implementation of heat pumps. Promotional programmes are being implemented by governments, utilities and manufacturers. Heat pumps are a powerful heating technology that can help governments to realise their CO_2 emission reduction goals. Utilities promote heat pumps because they enable them to gain and retain customers, as well as assist with load levelling.

Existing promotion programmes often do not distinguish between heat pumps for retrofit and applications in new buildings. Information about existing promotion programmes can be found in [1]. Concerning heat pumps for retrofit, the following comments can be made:

In **Austria**, there is no federal government programme for the support of heat pumps, but some provinces and communities offer financial support. Under the umbrella of this promotional programme, a number of provincial utilities are implementing their own local programmes. There is no focus on retrofit.

In **Japan,** load levelling is a very important issue. Therefore, the government of Japan promotes heat pumps with thermal storage, and thermally-driven heat pumps and absorption heat pumps. Furthermore, the Japanese government has defined new energy efficiency targets for domestic appliances in the Top Runner Programme. From October 2003, the target *average heating and cooling* COP for split-type air conditioners and heat pumps smaller than 2.5 kW heating capacity is 5.27. For heat pumps between 2.5 – 3.2 kW, the requirement is an average COP of 4.90 and for the 3.2 – 4.0 kW capacity range, a minimum average COP of 3.65 is required. As most heat pump sales are for replacement, no specific promotion of heat pumps for retrofit is required.

In **Norway**, the Norwegian Water Resources and Energy Administration (NVE) launched a new subsidy programme in 1998 for "Bioenergy and flexible heating systems". The main goals of the programme are to increase the number of energy-efficient and flexible heating systems (e.g. bivalent heat pumps), establish regional markets for bioenergy and increase the utilisation of waste heat from industry. This may have important implications for heat pumps.

In the **Netherlands**, the heat pump programme for 2000 – 2004 specifically stimulates applications in the most promising market segments, from an emission reduction and economic point of view. The priority segments were determined in consultation with market players in the various sectors: residential applications, commercial/institutional buildings and agriculture, respectively. Results from this consultation indicated that for residences, significant support should be given to both new and retrofit applications. In the commercial/institutional sector, on the other hand, the priority was given to applications in new buildings. Experience gathered in the projects in new commercial/institutional buildings will stimulate the market for retrofit as well.

The market for residential heat pumps has seven priority market segments, of which five are heat pumps for retrofit and two are applications in new buildings. Heat pumps for residential retrofit contribute 60% to the energy saving target for

2020. The targeted retrofit markets are: full renovation of private houses; replacement of gas-fired space and hot water heating systems in private houses; replacement of electric water heaters; replacement of gas-fired water heaters; and collective systems in apartment blocks. The commercial/institutional market has seven priority market segments as well, but retrofit in small offices with a cooling demand is the only priority segment which does not focus on new buildings.

The joint efforts of all market parties in **Switzerland** have resulted in 36% of the houses built in 1999 having a heat pump. For renovations, on the other hand, only 3% of the house owners chooses a heat pump as the new heating system. Therefore, retrofit is the focus of the programme of the ambient heat, waste heat and refrigeration of the Swiss Federal Office of Energy (SFOE). The programme stimulates technical developments leading to a monovalent heat pump suitable for the retrofit market and organised the competition "Swiss retrofit heat pump", see Section 4.3.2.

In the **UK,** the government (DTI/DETR) supports the UK Heat Pump Network, which joins around 300 heat-pump-interested individuals. The secretariat of the network prepares promotional material. A few electric utilities stimulate the use of heat pumps in buildings, and are gaining experience through field tests. The UK Heat Pump Association is also an important market player from industry. Its efforts mainly concern applications in commercial/institutional buildings. One of its activities is to give annual awards for installations and designs. There are no specific programmes related to retrofit.

In the **USA,** the government initiated the Federal Energy Management Program (FEMP), which aims to reduce the use and cost of energy in the federal sector by promoting energy efficiency, water conservation and the use of solar and other renewable energy sources, including ground-source heat pumps. The Geothermal Heat Pump (GHP) programme is one technology-specific arm of the FEMP. The aim of this programme is to harness the purchasing power of the federal government to transition GHP systems from their current status as proven but under-utilised technology to a mainstream energy-cost-saving measure in the 2000 – 2004 period. Utilities and energy service companies play an important role. Besides this programme, some utilities stimulate heat pumps in general. These efforts concern both applications for retrofit and for installation in new buildings.

2.3 Energy-saving potential

The purpose of a heat pump installation is to provide heating, and cooling, when required. Compared to conventional heating techniques, a heat pump saves energy, and thereby reduces CO_2 emissions. The energy saving potential is dependent of the amount of energy that is used for heating purposes, and that depends first and foremost on the climatic conditions and building standards. Secondly, it is dependent on the power plant efficiency, and the efficiency and emissions of competing heating systems.

The study *Environmental benefits of heat pumping technologies* [2] has shown that heat pumps significantly reduce CO_2 emissions, also when the full life cycle of the equipment and refrigerant emissions are considered. Assuming the world-average

CO_2 emissions for electricity generation, emissions from a heating-only heat pump with SPF 3.1 (SPF = seasonal performance factor) are:

- 25% lower than from a gas-fired boiler with efficiency 1.04 (LHV); and
- 45% lower than from an oil-fired boiler with efficiency 0.94.

CO_2 emissions at the power station are the most important factor for the impact of heat pumps on the greenhouse effect. If non-fossil-fuel energy sources or natural gas in combined-cycle plants contribute substantially to electricity generation, heat pumps offer even higher potentials for CO_2 emission reduction.

2.3.1 Climatic conditions

The heating demand is dependent on the difference between the outdoor air temperature and the desired indoor temperature. In northern European climates, the minimum outdoor temperature varies from -10°C on the west coast to -40°C in the inland mountain areas of the central and northern parts of Scandinavia. In the southern parts of Europe, Asia and North America, the minimum design outdoor temperature may be as high as 0ºC.

Temperature variations throughout a normal year may be presented as the degree day curve or a duration curve for the ambient temperature. Figure 2.2 shows the profiles of temperature duration for annual ambient temperatures varying from -3°C to +18°C.

The yearly mean temperature may be the main parameter for choosing the representative duration curve for different locations. The duration curves will vary substantially, depending on whether the building is located on the coast or inland.

The lowest annual temperature curves represent inland Arctic regions. Due to the warm Gulf stream, a coastal climate in the north of Norway will have significantly higher temperatures in the coldest winter season than inland regions at the same latitude.

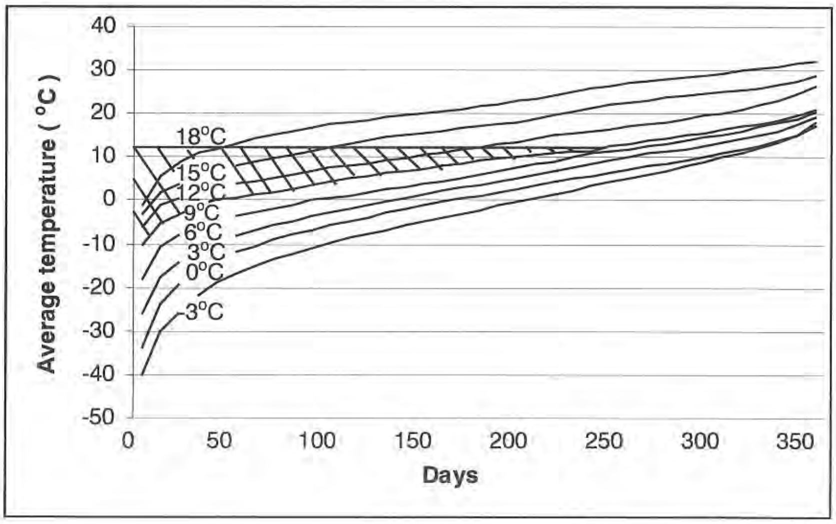

Figure 2.2 *Temperature duration curves for different mean annual temperatures in inland climates.*

The total heating demand which is required in a 'normal year', is proportional to the area between the temperature duration curve and the outside air temperature above which no heating is required, as shown in Figure 2.2. The Figure shows the relevant area for 9ºC annual average and 12ºC as the highest temperature as an example. Above this temperature, the heating installation is switched off, as the heating demand is covered by internal heat generated from lighting, computers and from people as well as from solar radiation.

Cold regions normally have a long heating season, and high utilisation time is an important factor for the heat pump's economy.

In addition, use of space cooling is also increasing in cold regions. Modern buildings with glazed spaces have high heat gains from solar radiation, and internal heat gains from computer installations etc. are also rising. The value of proper indoor air quality is indisputable, and it is acknowledged that investments in good air-conditioned indoor climate are profitable in commercial and institutional buildings.

Due to the increased comfort requirements in buildings, heat pumps for heating and cooling will in the future find extended use in different climates. As an example, heating and cooling demands are represented by the number of degree-days below and above 15°C at different locations in the western parts of Europe, heating degree days and cooling degree days respectively, Figure 2.3 (see Appendix 1 for a map). The dotted line represents the cooling demand if internal heat from lights, computers etc. stands for another 5°C temperature increase of the indoor air.

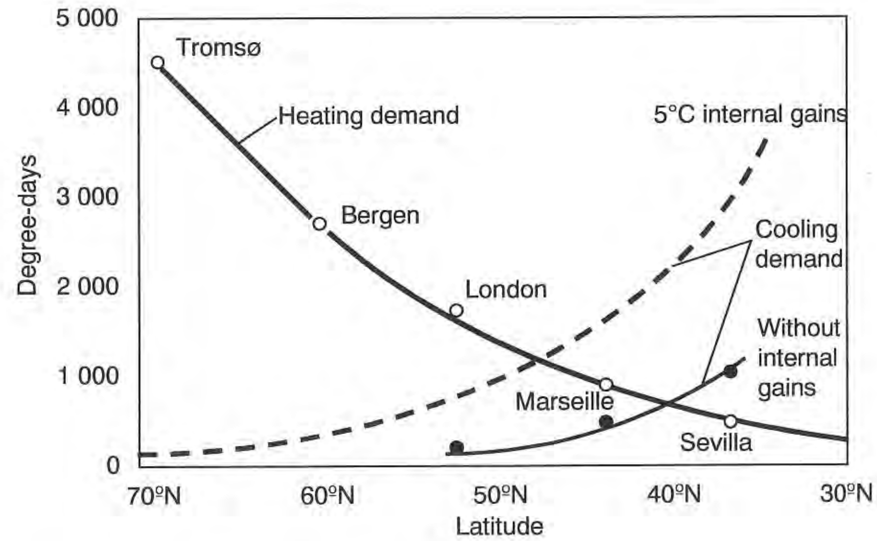

Figure 2.3 *Heating and cooling demands in European coastal and semi-coastal climates.*

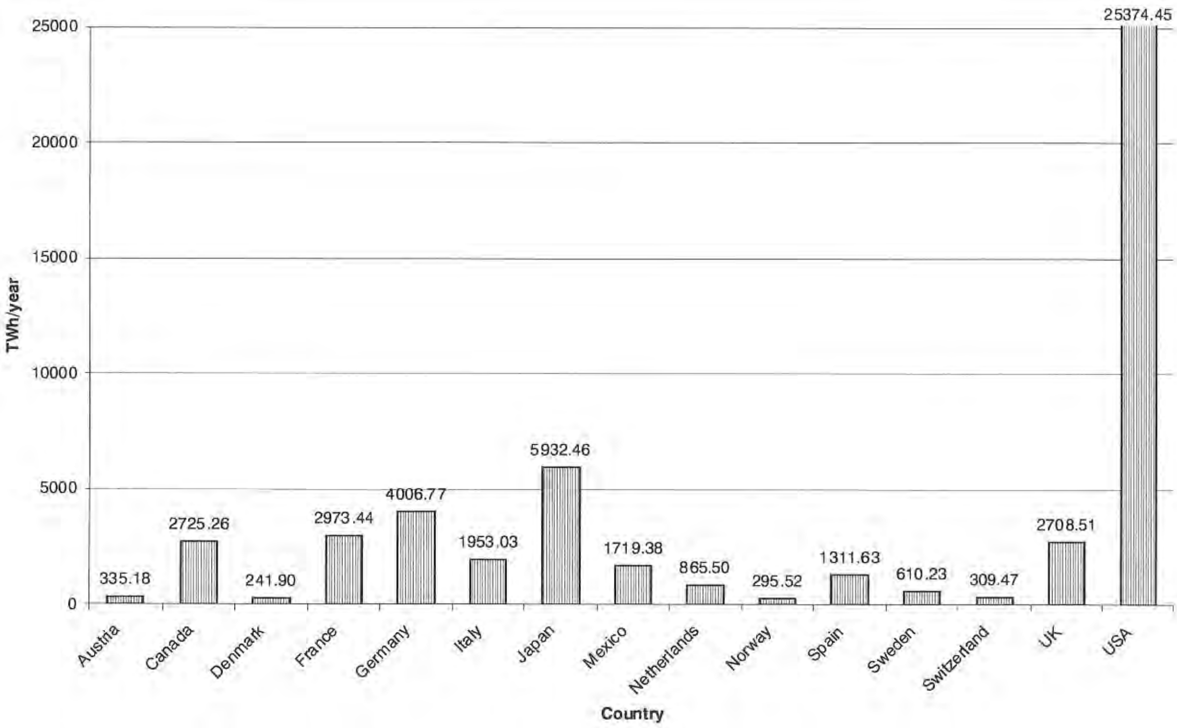

Figure 2.4 *Total annual primary energy supply, 1998 [7].*

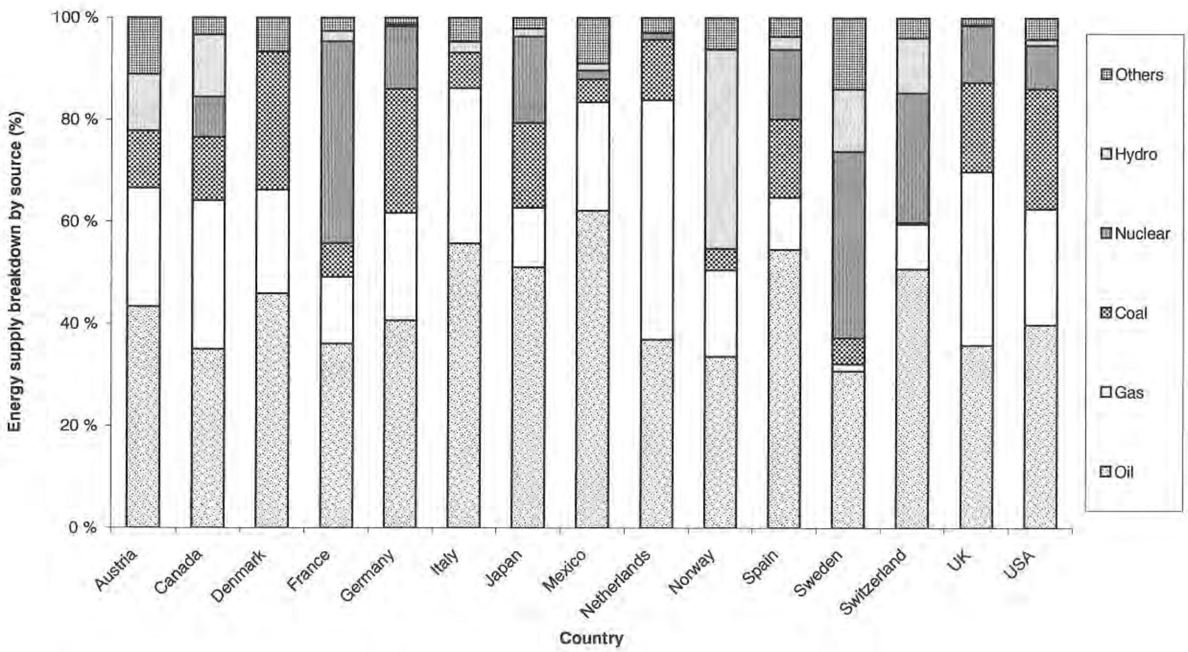

Figure 2.5 *Breakdown of total primary energy supply by source 1998 [7].*

2.3.2 Energy situation

The energy situation differs considerably from one country to another, especially with regard to available energy resources and prices. These conditions will affect the competitive power of heat pumps compared with traditional heating and cooling systems. Most of the information regarding the energy situation is taken from IEA statistics [7].

Figure 2.4 shows the annual total primary energy supply, and Figure 2.5 the energy supply breakdown by source for the IEA Heat Pump Programme (HPP) countries.

In the majority of countries, more than 70% of the primary energy demand is met by fossil fuels. Exceptions are France, with a large number of nuclear power plants, Norway, with large hydro power resources, and Sweden and Switzerland, with a combination of both.

2.4 Potential for CO_2 emission reductions

Heat pump installations affect the environment in two ways:

- Use of fossil fuels is reduced and, consequently, greenhouse gas emissions are considerably reduced (between 10% and 45% compared to gas- and oil-fired boilers).
- Halocarbons that are used in most heat pumps will have negative effect on the environment when released during service, disposal or through leakage. CFCs and HCFCs, which are regulated by the Montreal protocol, have both an ozone depleting potential (ODP) as well as a global warming potential (GWP). The HFCs, however, do not influence the ozone layer, but they are relatively strong 'greenhouse gases'.

The impact of refrigerants on the total equivalent warming impact (TEWI) of heat pump systems is usually small. Assuming world-average CO_2 emissions from electricity generation, emissions of refrigerants only contribute up to about 10% to the TEWI of a heat pump.

2.4.1 Primary energy mix for electricity generation

Heat pumps use less primary energy than conventional heating systems. Therefore they are capable of reducing both the annual energy consumption and emissions from burning fossil fuels. Almost all heat pumps currently installed are electrically driven. Therefore, the fuel mix for electricity generation and the efficiency of power stations are important. If nuclear power, hydropower, natural gas and/or renewable energy dominate the electricity generation mix, then electric heat pumps offer substantial reduction of CO_2 emissions if they replace a fossil-fuel-fired system.

Figure 2.6 shows the primary energy mix for electricity generation in the HPP countries.

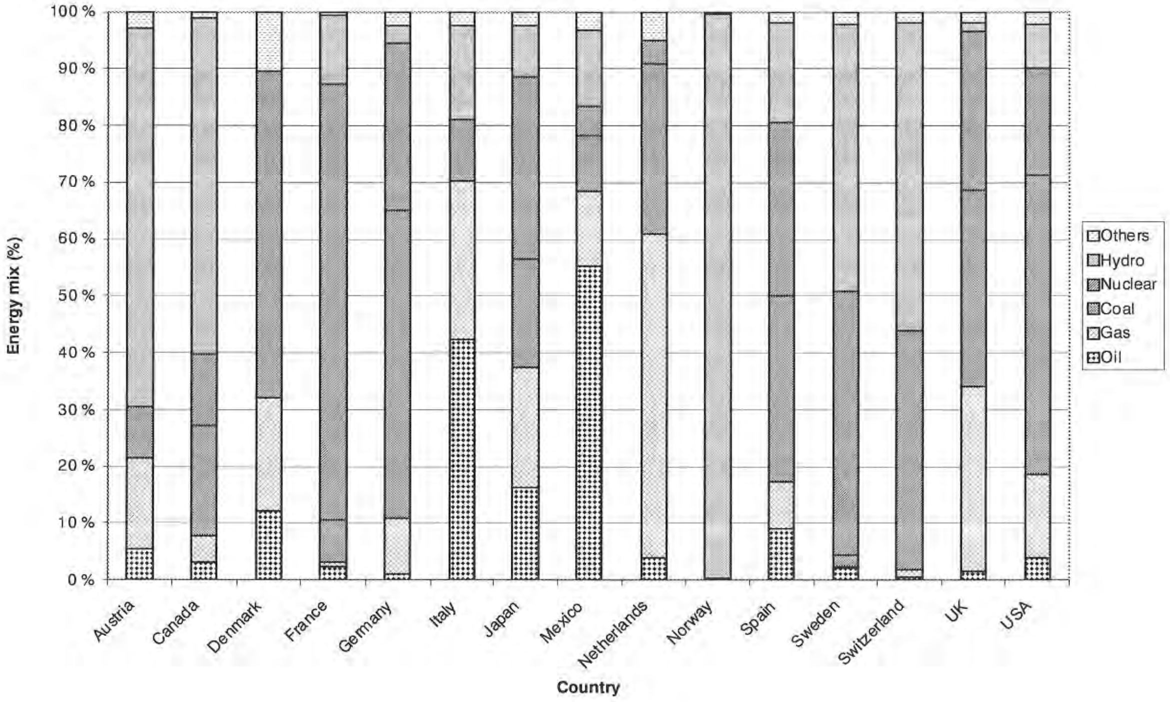

Figure 2.6 *Energy mix for electricity generation 1998 [7].*

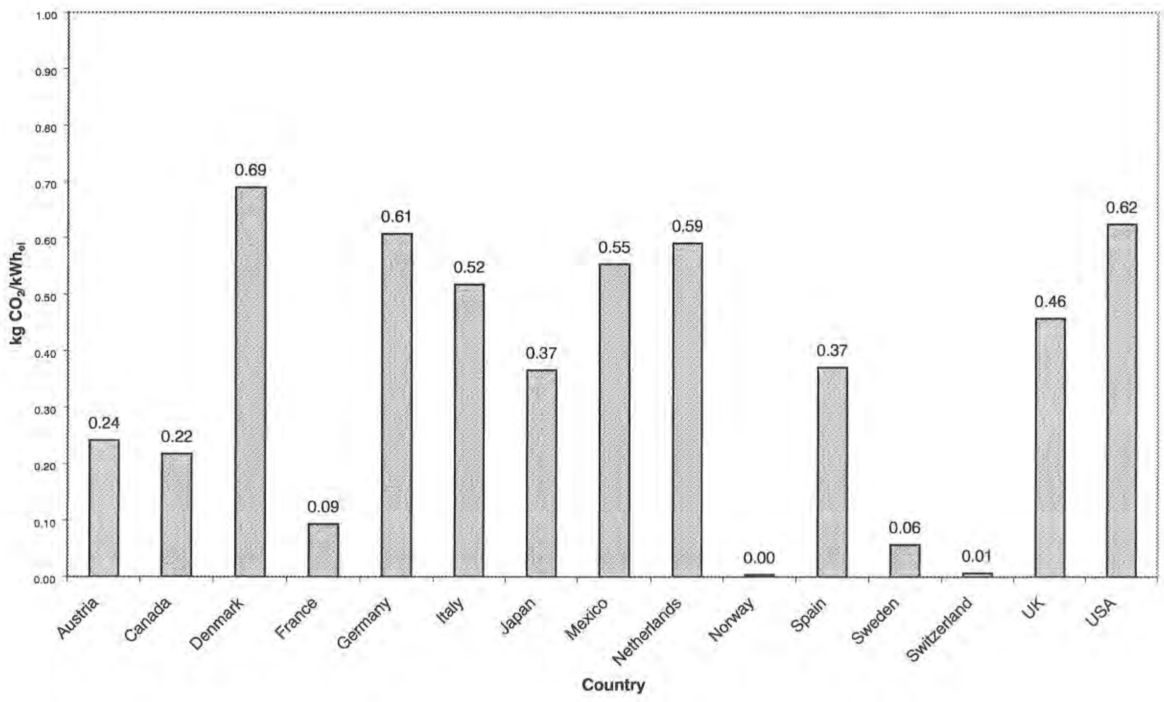

Figure 2.7 *CO_2 emissions from electricity generation 1998 [7, 8].*

The 1998 fuel mix differed significantly across these countries. In France, Norway, Sweden and Switzerland, more than 90% of the electricity comes from hydropower and nuclear power plants. In Denmark, Greece, Italy and the Netherlands, over 80% of production is from fossil fuels. Production from other sources is generally minor. Only Denmark (which uses biomass and wind) generates over 5% of its electricity from renewable sources other than hydropower.

Figure 2.7 shows an approximation of the CO_2 emissions from electricity generation in 1998. These data were calculated on the basis of the electricity produced. In countries where a significant amount of the electricity production is from combined heat and power plants, this caused a deviation, as the useful heat produced is not taken into account.

2.4.2 The impact of heat pumps on global warming

Heat pumps for retrofit are normally installed as replacements for fossil-fuel heating or direct electric heating. In countries where electricity is produced by fossil fuels, heat pumps have the potential of consuming 30 – 50% less primary energy than conventional heating systems, and they can also be used for air conditioning. In countries where electricity is to a large extent generated in nuclear or hydro power plants, the CO_2 emission reductions compared with fossil-fuel-fired heating systems is considerably higher, typically 60 – 80%.

The formation of CO_2 is increased considerably by burning oil compared to gas, and even more by using coal as fuel. Therefore, the impact of heat pumps on the greenhouse effect is on the one hand dependent on what kind of fossil fuel is used for heating, and on the other hand on the energy mix for electricity generation. This dependency is shown in Figure 2.8 [9] where an electric heat pump and fossil-fuel-fired boilers are compared. In addition, the impact is also dependent on the efficiency of the boiler and the COP of the heat pump.

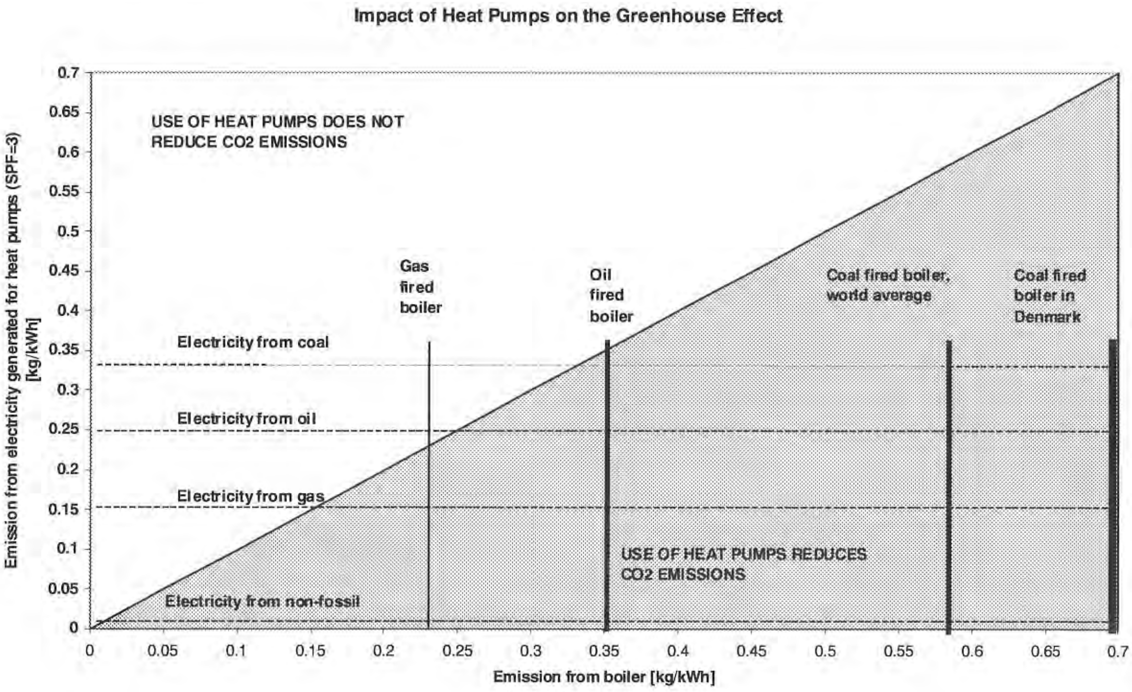

Figure 2.8 *CO_2 emissions from heat pumps (SPF = 3, various sources of electricity) compared with emissions from fossil-fuel-fired boilers.*

The emissions from coal- and oil-fired installations in Figure 2.8 are based on efficiencies for electric power plants of 35% and 40%, respectively, and on efficiencies for coal- and oil-fired boilers of around 60% and 80%, respectively.

Refrigerants used in heat pumps are often greenhouse gases. CFCs, HCFCs and HFCs are all greenhouse gases. The impact of refrigerants on the total equivalent warming impact (TEWI) of heat pump systems is usually small. Assuming world-average CO_2 emissions from electricity generation, emissions of refrigerants only contribute up to about 10% to the TEWI of a heat pump. The percentage is only higher when CO_2 emissions for electricity production are very low, for example in Norway and Switzerland.

The Heat Pump Programme brochure from 1997 stated: "Heat pumps can cut global CO_2 emissions by more than 6%". This potential will be realised when 50% of the buildings are heated with state-of-the-art heat pumps, which save at least 30% CO_2 emissions compared to conventional heating methods. This message is still valid today, but to realise the potential, the retrofitting market for heat pumps must be increased.

3 Barriers facing heat pumps for retrofit

There are several barriers facing the use of heat pumps for retrofit:

- High distribution temperatures in the traditional hydronic heating systems, with:
  - Design temperatures much higher than the high-temperature limits for conventional heat pump units; and
  - High temperature lifts, leading to lower heat pump efficiencies. Also,
- The cost-effectiveness of heat pumps tends to be lower in retrofit situations. The main reason is that the energy cost savings are lower, due to lower efficiency. The heat pump installation may also require extra investments in a machinery room, as well as in tubing, automation and electrical installation compared with new building installations.

3.1 Heating and cooling distribution systems

This section discusses distribution systems in use in various climates and building traditions. It provides the background for a further discussion of market barriers in subsequent sections. More extensive information on distribution systems in various countries can be obtained from [10].

- In the USA and Canada, ducted air systems have a strong market position. In regions without a cooling demand, hydronic systems are also used.

- In northern, western and central Europe, hydronic systems for heat distribution dominate, except in Norway, where direct electric heating still has a strong market position. In Finland, direct electric heating with electric radiators and/or electric floor heating, or with hydronic heat distribution is very popular. Cooling is usually not installed in residences.

- In southern Europe, heat distribution is mostly by hydronic systems, or locally (per room). Cooling is increasingly installed, both with and without a central cooling distribution system.

- In Japan, ductless split room air conditioners are popular. Such reversible heat pumps supply hot and cold air directly to the conditioned rooms.

3.1.1 Design temperatures of different heating and cooling systems

Design temperatures of different hydronic heating and cooling distribution systems in the residential and commercial building sectors can generally be divided into three main categories, while the design temperatures for air systems are divided into two main ranges, as shown in Table 3.1.

Design temperatures in hydronic distribution systems are divided into different levels depending on the temperature requirements in different heating and cooling distribution systems. For existing buildings, the traditional design temperatures for the supply and return water were 80/60ºC or 90/70ºC.

Table 3.1 *Design temperatures for various heating and cooling distribution and supply systems.*

Application	Supply temperature (ºC)
Hydronic heating systems:	
• High-temperature radiators	60 – 90
• Low-temperature radiators	45 – 60
• Radiant floor heating	30 – 45
District heating systems	
• Hot water	70 – 100
• Hot water/steam	100 – 180
Space cooling systems	
• Chilled water	5 –15
• District cooling	5 – 8
Air distribution	
• Air heating	30 – 50
• Air cooling	10 – 15

Air distribution systems with delivery temperatures of 30 – 50ºC are quite suitable for heat pump applications, while high-temperature hydronic systems result in low COP as well as possible design and operational problems for heat pumps. Consequently, the focus will mainly be on heat pumps for retrofit in hydronic systems.

3.1.2 Temperature control of hydronic systems

In order to reduce thermal losses, the distribution temperature level is normally reduced with increasing outdoor temperatures. When the heating installation is to be retrofitted with a heat pump, this kind of temperature control is essential.

Figure 3.1 shows a typical regulating control curve for the supply water temperature, and the corresponding supply water temperature duration curves are presented for three different climates:

- Mid-Scandinavian inland climate like Lillehammer, Norway, with design outdoor temperature of -25ºC and 3.5ºC average annual temperature;
- Mid-continental climate like Bremen, Germany, with -15ºC design outdoor temperature and 8ºC average temperature; and
- A Mediterranean climate like Athens, Greece, with design outdoor temperature of -5ºC and 18ºC average temperature.

In this case, the heating season is defined to begin below +15ºC ambient air temperature, and the forward water temperature is reduced linearly from 80ºC at design outdoor air temperature to 30ºC at +15ºC ambient air temperature. As shown in Figure 3.1, the temperature duration curves are quite similar for the two locations of the middle and northern parts of Europe, while the hot climate in Athens means a shorter heating season and lower water temperatures.

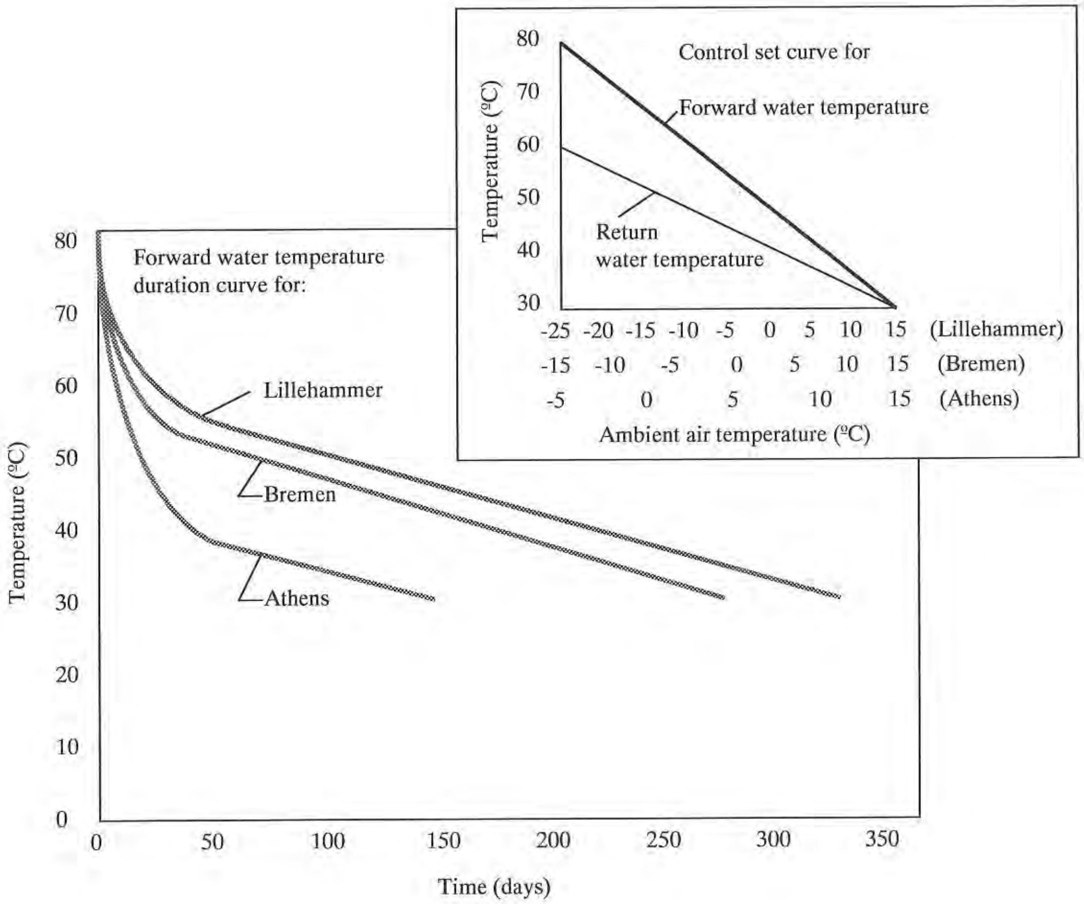

Figure 3.1 *Control set curve (upper part) and forward water temperature duration curve (lower part) for three different locations of high-temperature hydronic heat distribution system.*

Figure 3.1 makes it clear that the supply and return temperatures can decrease considerably with increasing ambient temperatures. The restriction of heat production from the heat pump in such a heat distribution system is dependent on the operating temperature limit of the heat pump.

3.2 Heat pump operating temperature limit

The upper temperature limit of a heat pump is affected by several factors, such as:

- Heat source;
- Working fluid;
- Maximum operating pressure; and
- Design of the heat pump.

The traditional operating pressure for refrigeration and heat pump equipment is 25 bar. In Table 3.2, the corresponding saturation temperatures (T_{sat}) and critical temperatures (T_{crit}) are given for a number of refrigerants.

Table 3.2 *Saturation temperatures for some refrigerants.*

Temperature (ºC)	R-404A	R-407C	R-410A	R-507	R-134a	R-290 Propane	R-717 NH_3
T_{sat} at 25 bar	53	55 – 59	41	52	78	68.3	58
T_{sat} at 1 bar	-46/-47	-37/-44	-52	-47	-26	-42.1	-3.3
T_{crit}	74.4	86.4	71.8	71.0	100.6	96.7	130.0

The condensing temperatures at 25 bar are not always accepted as the high temperature limit. A number of manufacturers use a safety margin, and there are also other factors like the discharge gas temperature limit, which may be a restriction on heat pump operation.

Most heat pumps with refrigerant mixtures (R-404A, R-407C, R-410A and R-507) operate with 50°C to 55°C as the maximum forward water temperature from the condenser, while single-stage R-134a heat pumps may operate with 55°C to 60°C as the maximum. A number of heat pump manufacturers are developing R-134a heat pump systems which may operate at higher temperatures. It is clear that the operating temperatures of most HFC heat pumps are not adapted to monovalent operation for retrofit with high-temperature hydronic heat distribution systems.

3.3 High temperature lifts versus heat pump efficiency and operational safety

Heat pumps operate most efficiently when the temperature difference between the heat source and heat sink is small. The heat extraction and delivery temperatures are therefore very important for the performance of a heat pump.

The efficiency is represented by the coefficient of performance (COP), defined as the ratio of heat delivered by the heat pump to the electricity supplied to the compressor. The COP can be expressed as a function of the operating temperature limits:

$$COP = \eta_C \cdot \frac{T_1}{T_1 - T_2}$$

where η_C is the Carnot efficiency of the heat pump process;
T_1 is the heat sink temperature (K); and
T_2 is the heat source temperature (K).

The upper curve in Figure 3.2 shows the COP for an ideal (reversed Carnot cycle) heat pump as a function of the temperature lift, while the lower curves show the COP of real heat pumps operating with Carnot-efficiencies varying from $\eta_C = 0.4$

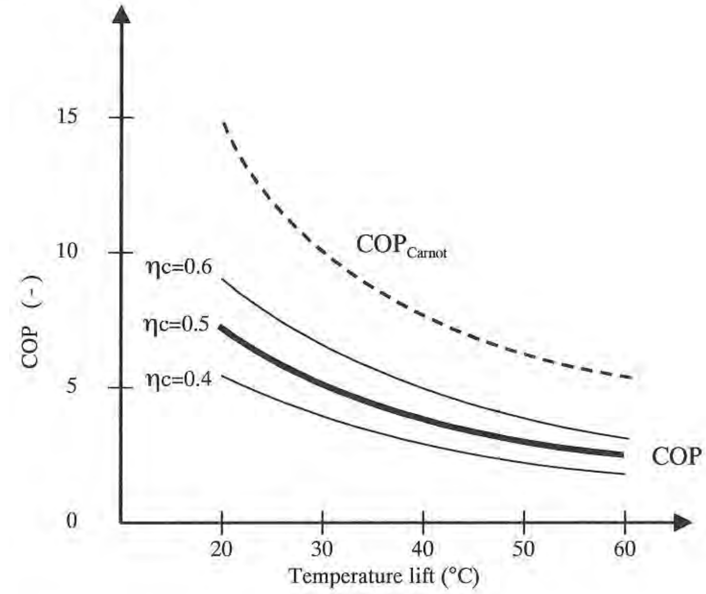

Figure 3.2 *COP as a function of temperature lift.*

(smaller heat pumps) to $\eta_C = 0.6$ (larger heat pumps in commercial buildings). The temperature of the heat source is 0ºC.

In addition to the reduced COP, which means reduced energy saving, the increased temperature lift also affects the operating conditions of the compressor, see Figure 3.3. All compressors have to operate within certain limits with regard to evaporation and condensation pressures, and below a maximum discharge gas temperature in order to avoid risk of compressor failure. Figure 3.3 illustrates what happens to the discharge gas temperature when the condensing temperature is raised from 50ºC to 60ºC for an R-22 heat pump with reciprocating compressors and with 0ºC evaporation temperature.

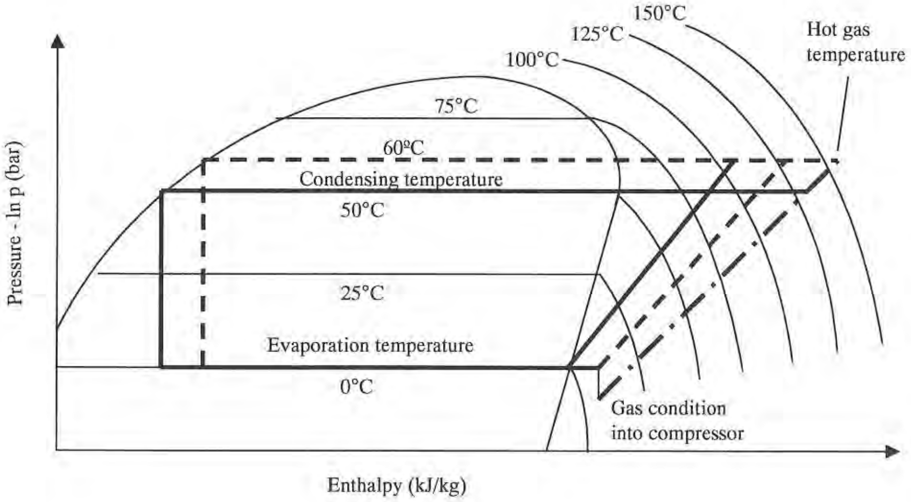

Figure 3.3 *Influence of temperature lift and suction gas condition on the discharge gas temperature out of the compressor.*

If the heat pump is equipped with a flooded evaporator, with saturated suction gas into the compressor, the increased condensing temperature means a rise of the discharge gas temperature from about 90ºC to 110ºC, which are safe operating temperatures for the compressor.

If the heat pump is equipped with a dry evaporator, with liquid injection by a thermostatic expansion valve, with 10ºC superheat, the discharge gas temperature is raised from 110ºC to 130ºC. This resulting temperature is regarded by most manufacturers to be close to the maximum temperature limit for safe operation of the heat pump.

If there is also a pressure reduction (or reduced heat source temperature), so that superheated gas with -10ºC evaporation temperature enters the compressor, the discharge gas temperature is raised from 130ºC to more than 150ºC when the condensing temperature is increased from 50ºC to 60ºC. This will probably lead to compressor failure after a short period of operation.

On the low-temperature side of the heat pump, the temperature level is first of all determined by the available heat source. Heat pumps may extract heat from a number of heat sources, and water-based or ground-coupled heat pumps give a relatively stable temperature level throughout the year, which means safe operating conditions for the heat pumps. The average temperature level is also higher than the ambient air temperature, so seawater and ground heat sources are therefore normally preferred for large heat pump systems. On the other hand, ambient air is available everywhere. It is, therefore, a very important heat source, especially for small heat pump systems.

3.4 Economy of heat pumps for retrofit

Profitability is the most important factor when evaluating heat pump installations in competition with other heating systems.

The economy of heat pumps for retrofit varies significantly due to the market differences between countries. There are four factors which play a key role:

1. Specific investment cost (USD/kW heating capacity);
2. Coefficient of performance (COP);
3. Equivalent operating time (hours per year); and
4. Energy prices (USD/kWh).

3.4.1 Specific investment cost

The size and complexity of the heat pump influence the specific investment cost. Normally, the specific investment decreases with increasing capacity of the heat pump. By installing a heat pump for combined heating and cooling purposes, the specific heat pump investment cost is reduced, by cancelling the need for a separate cooling installation.

Figure 3.4 shows an example of the specific investment cost (USD/kW heat output) for a conventional oil-fired boiler, for a water-to-water heat pump and for the complete heat pump installation including a water-based heat source and an auxiliary boiler [11].

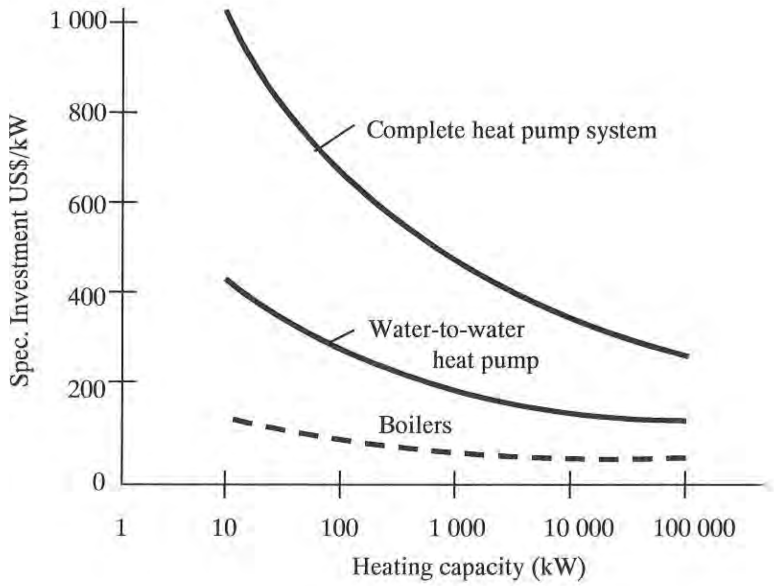

Figure 3.4 *Specific investment costs for a water-to-water heat pump system and a conventional oil-fired boiler as a function of heat output (kW) [11].*

Heat pumps normally cost 1.5 to 5 times more than a gas- or oil-fired heater of the same thermal capacity, but the investment ratio is more moderate if the total energy system is considered.

The additional investment cost of a heat pump system has to be justified by energy cost savings during its useful service life. Since the energy efficiency of retrofitted heat pumps may be lower than for application in new buildings, the payback period may be longer.

3.4.2 Energy efficiency (COP)

Table 3.3 shows typical COPs for water-to-water heat pumps operating with various heat distribution systems. The temperature of the heat source is 5ºC. The higher the COP, the lower the operating cost.

Table 3.3 *COP of a water-to-water heat pump versus the distribution/return temperature.*

Heat distribution system (design supply/return temperature)	COP
Floor heating (40ºC /35ºC)	4.0 – 5.0
Low-temperature radiators (55ºC /45ºC)	3.5 – 4.0
Conventional radiators (80ºC /60ºC)	2.5 – 3.0

Conventional radiators only enable a moderate COP. This relates to relatively low energy cost savings in the case that an existing conventional radiator system is retrofitted with a heat pump.

3.4.3 Operating time

The equivalent operating time is defined as the time in hours that the heat pump has to run at full capacity in order to cover the annual heat production of the heat pump. Since the heat pump is generally more expensive to install than alternative heating systems using fossil fuel or electricity directly, the utilisation time (equivalent operating time) is a most important factor with regard to the heat pump's economy.

The heat load duration curve is dependent on several factors, mainly the climatic conditions, and the type of building, with regard to degree of insulation, the degree of ventilation and the indoor air temperature requirements. Figure 3.5 shows the heating load duration curves for four different climates and equivalent operating hours for a bivalent system, where 50% of the maximum heating capacity can be covered by the heat pump. Since the maximum design load will occur only for short periods, the average relative productivity of the heat pump can be improved by designing it for a reduced capacity, and satisfying the occasional peaks by some cheaper system.

1	**Arctic regions (example: Tromsø)**	
	Design outdoor temperature:	-10 to -40ºC
	Average annual temperature:	0 to 3ºC
2	**Mid-Scandinavian region (example: Oslo)**	
	Design outdoor temperature:	-10 to -25ºC
	Average annual temperature:	3 to 7ºC
3	**Continental/Mid-European region (example: Bremen)**	
	Design outdoor temperature:	-5 to -15ºC
	Average annual temperature:	7 to 14ºC
4	**South-European region (example: Athens)**	
	Design outdoor temperature:	0 to -5ºC
	Average annual temperature:	14 to 20ºC

From Figure 3.5, it is clear that the equivalent operating time (τ) increases dramatically for the northern locations. It is nearly doubled in Tromsø, Norway as compared to Bremen, Germany, and is more than six times higher in Tromsø than in Athens. This means that a heating-only heat pump system in Tromsø can carry much higher investment for the same capacity than in the southern parts of Europe, when the energy price is the same in both cases. In the southern countries, however, the main reason for installing a heat pump is to cover the cooling demand during summer. The market for retrofit with heat pumps should be easier in Tromsø than in Bremen.

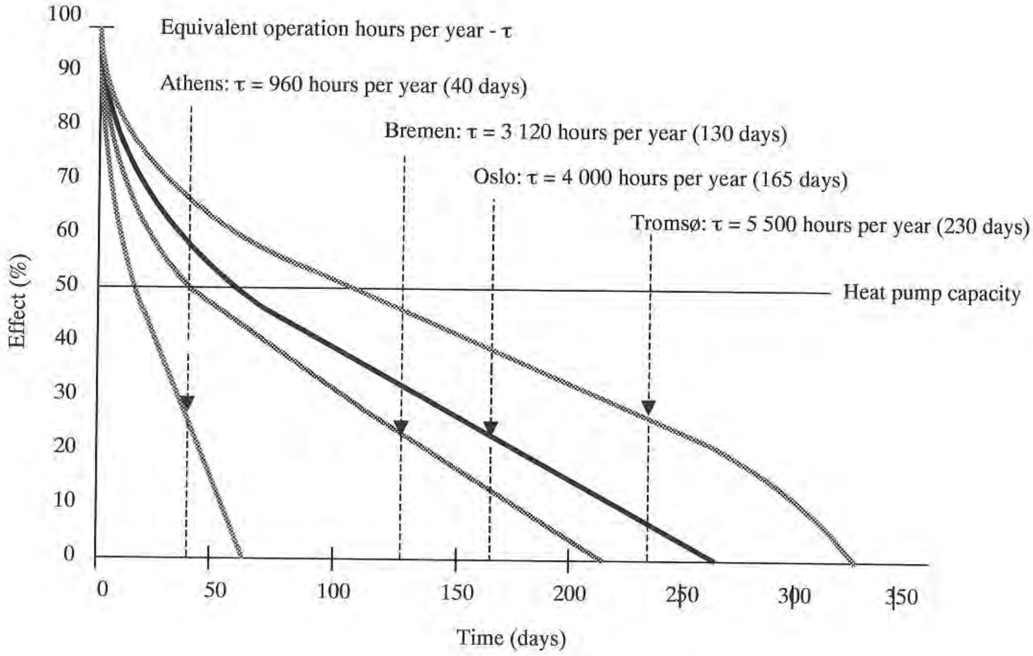

Figure 3.5 *Heating load duration of four different sample climates.*

3.4.4 Energy prices

The economy of heat pumps is highly dependent on energy prices. In most European countries, electrically-driven heat pumps have to compete with oil- or gas-fired heating systems. As electricity prices are high in relation to gas or fuel oil, the heat pump efficiency has to be improved in order to obtain substantial energy cost savings. In Norway, as well as in some other countries with relatively cheap electricity from hydroelectric power (or nuclear energy), direct electric heating is a serious competitor to the heat pump.

The price ratio of electricity to fossil fuel affects the economy of heat pumps compared to other heating and cooling systems. The evolution of these energy prices is an important factor in the heat pump market situation and its future development.

Table 3.4 *Average energy price ratios 1998 [12].*

	Residential	
Country	**elect./oil**	**elect./gas**
Austria	3.0	2.0
Czech Republic	1.6	2.9
Denmark	3.2	3.5
Finland	3.5	6.1
France	3.7	3.1
Germany	5.8	
Greece	2.7	5.9
Italy	2.0	2.4
Netherlands	3.0	3.7
Norway	1.3	
Spain	5.2	3.0
Switzerland	6.5	3.2
UK	5.4	3.8
USA	3.4	3.3

Wide discrepancies in energy prices exist between countries. In some countries there is a cost ratio of electricity to oil of 3.5 to 4. The heat pump must have an SPF of roughly 3.5 or 4 in order to become economically viable, and this is not always possible for retrofit heat pumps in high-temperature hydronic systems. As the electricity-to-oil price ratio increased in Austria at the end of the eighties, bivalent heat pump systems disappeared from the market because the efficiency of such systems is too low to ensure energy cost savings.

On the basis of Table 3.4 above, the average retrofit heat pump with a conventional radiator system (Section 3.4.2) would only achieve energy cost savings in Austria (replacing a gas-fired boiler, a rare heating system in Austria), Czech Republic, Greece (replacing an oil-fired boiler), Italy and Norway. In all other countries, this retrofit heat pump would lead to an energy cost increase and would not be economically attractive. The average new heat pump system can be combined with a low-temperature distribution system and will achieve energy cost savings in nearly all countries.

It should be mentioned that individual cases may differ considerably from the average case presented above. Especially the electricity to drive the heat pump can cost considerably less than average, because of incentives or block tariffs.

3.5 Lack of space

A serious barrier to retrofitting with heat pumps can be lack of space. The installation space which is normally used for a gas-fired boiler may be too small to accomodate a heat pump. Also, the installation room should not be situated too closely to bedrooms, for example, to prevent noise problems. It is important that heat pumps for the retrofit market are well adapted to national norms as regards their installation space requirements.

3.6 Selection of heat source

Of a different order are space problems to accommodate the heat exchanger which extracts (or rejects, in the case of cooling) heat outdoors.

- Outdoor air is the easiest heat source to use in retrofit cases. A location for the outdoor air-to-refrigerant heat exchanger can always be found. The disadvantage of outdoor air is that its temperature is inversely proportional to the heating or cooling demand indoors.

- Exhaust air can be used as a heat source when an exhaust ventilation system is in place. The heat extracted from exhaust air can be used for heating domestic hot water. In most cases, the heat extracted from exhaust air is not sufficient for residential space heating. The building must accommodate the exhaust-air-to-refrigerant heat exchanger.

- Ground or groundwater heat exchangers are excellent heat sources, but the necessary digging work may be a disadvantage in retrofit cases, e.g. when this (temporarily) destroys a garden. In densely populated areas, the area around a building may be insufficient for a horizontal ground heat exchanger. Vertical borehole heat exchangers and groundwater heat exchangers require less area. In the case of new buildings, groundwater wells are often shared between several houses to spread the cost. Such sharing is less practical in retrofit cases. The cost of a vertical borehole heat exchanger or a groundwater heat exchanger system may be a serious burden.

- Surface water and industrial waste heat are excellent heat sources. The limited availability of both in residential areas is the main barrier to their increased use, both for new buildings and in retrofit cases.

The conclusion of the above is, that for both cost and space reasons, the heat source for heat pumps used for retrofit will mostly be outside air.

4 Overcoming the barriers to retrofitting

Since the main problem related to heat pumps for retrofit is the high distribution temperature, the challenge is then to retrofit the distribution system for a lower temperature level, or to build a heat pump which can manage the high temperature level. It is also possibility to avoid these problems by selecting buildings or heating applications which are especially suitable for heat pumps, or to install a heat pump with its own distribution system separate from the existing hydronic system.

4.1 Reduction of temperature lift

There are several ways to reduce the heat demand, and thereby the required supply water temperature in existing radiators. Table 4.1 shows at which temperatures an original 80/60ºC system can operate with different kinds of retrofit actions in existing buildings. The measures include improved temperature controls and improved insulation of the building envelope.

Table 4.1 *Possible temperature reduction measures in existing houses in Sweden [13].*

Year built	80/60ºC system can operate with	Measure
1930 – 1950	55/40ºC	Better regulation, improved u-value (heat transfer coefficient) from 0.9 – 0.4 W/m^2K, change to triple glazing, reduction of room temperature, air change rate 0.5 /h.
1951 – 1965	55-43ºC	Better control, improved u-value from 0.7 – 0.4 W/m^2K, sealing windows, reduction of room temperature, air change rate 0.5 /h.
1966 – 1977	67/52ºC	Better control, reduction of room temperature.
1978 – now		Adaptation to low-temperature system must be done by increasing the radiator surface, which is expensive.

4.1.1 Improved insulation standard

The temperature level of the hydronic heat distribution system is highly dependent on the heat demand of the building, which is dependent on the standard of insulation of walls and windows. In recent years, the tendency has been to increase insulation standards in most countries. In Norway, for example, the building codes required a heat transfer coefficient of u = 0.45 W/m^2K in walls in residential buildings in the 1970s. In the codes of 1987, the u-value in new building was reduced to 0.3 W/m^2K. Since the last revision in 1997, the codes now require 0.22 W/m^2K or lower u-values in new buildings, which is less than 50% of the values demanded by the code of 25 years ago.

The increased insulation standard applies to new buildings, but it also means reduced heat demands in existing buildings which are retrofitted to the same standard.

4.1.2 Removal of automatic temperature night setbacks

A traditional way of saving energy in commercial and institutional buildings with hydronic heat systems was to implement a temperature setback system to lower the room temperature at night. The boilers had to be designed to cover the maximum heat demand for raising the room temperature during the morning. This was an excellent way of saving energy in traditional heating installations with oil-, gas- or electrically-heated boilers.

However, the same practice is bad when using bivalent heat pump systems. This is explained as follows. At certain ambient temperatures, the indoor temperature-raising operation in the morning may require more heat input than the heating capacity of the heat pump, so the auxilliary boiler is activated. If the heat pump is big enough to cover the heating demand at constant temperature, day and night, use of the night setback system may lead to energy losses instead of energy savings. In any case, the supply temperature must be increased due to the increased heating demand in the morning. Therefore, with bivalent heat pump systems, it is recommended to operate at constant room temperature, both during the day and at night, in order to reduce the heat distribution temperatures as much as possible.

4.1.3 Retrofitting low-temperature distribution systems

Introducing low-temperature distribution systems is another measure to improve the operating conditions of the heat pump. One way to overcome the problems with high distribution temperatures is to install additional heat transfer surfaces in specific rooms through larger radiators or more efficient heat exchangers.

The most efficient type of heat distribution system for heat pumps is a low-temperature floor heating system. In existing buildings, it may be possible to retrofit a floor heating system by installing tubes in the ceiling from the room below where the floor area is to be heated. It may be much more expensive to install the floor heating system by removing and refitting the floor itself.

It is rather difficult to install floor heating systems in existing buildings, but one can often install a new hydronic wall-heating system, typically combining it with reinsulation of the wall. Technically, hydronic wall-heating system construction is quite similar to that of floor heating systems. However, there are of course restrictions with regard to the use of the walls after such an installation.

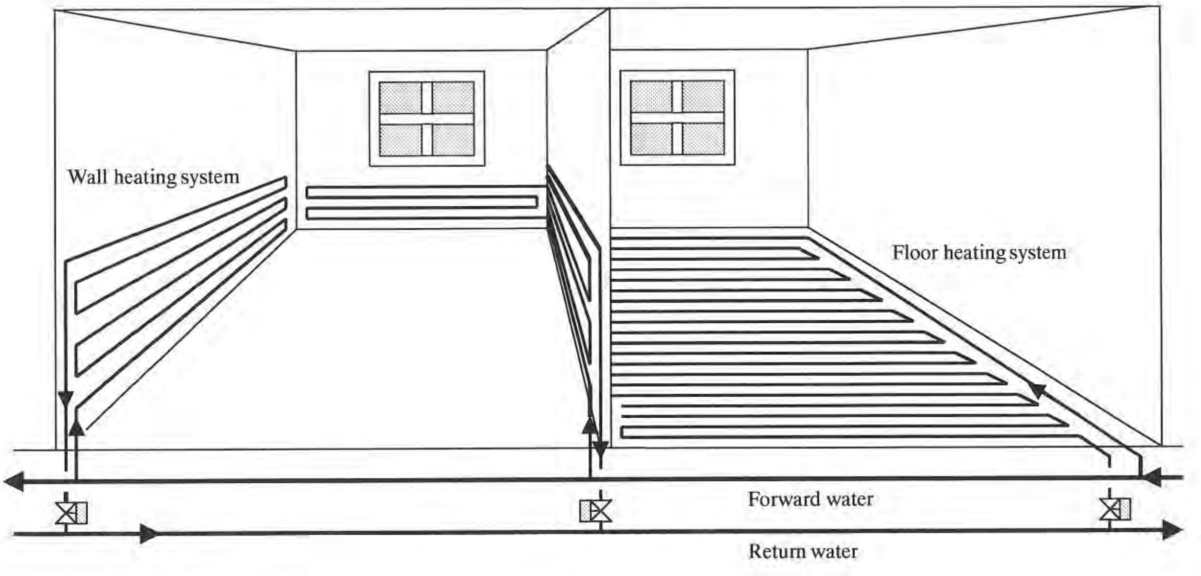

Figure 4.1 *Wall and floor heat distribution systems.*

4.2 Bivalent heat pump systems

Heat pump systems are often designed as bivalent systems, i.e. with the heat pump designed to cover the base heating load, while an auxiliary heating system covers the additional peak (supplementary) heating demand. This limits the maximum operating temperature required from the heat pump.

4.2.1 Design of bivalent heat pump systems

In a hydronic heat distribution system with 80/60°C as forward/return water temperatures, a heat pump designed to cover 50% of the total heating capacity must operate with 70°C forward water temperature at design conditions. The only commercial heat pump system for installations in the range of about 150-300 kW, which can cope with this condition, is a two-stage ammonia heat pump with 40 bar reciprocating compressors at the high-pressure stage. For larger systems, two-stage R-134a centrifugal compressor heat pumps are also available. For other kinds of heat pump installations, the capacity of the heat pump must be reduced when the ambient air temperature is reduced, as shown in Figure 4.2, and more auxiliary heating will be requested.

The heat load duration curve represents the Lillehammer climate (see Section 3.1.2). The area below the heat pump heat production curves represents the annual heat production from the heat pump. The area above the heat pump heat production curves up to 100% capacity represents the annual heat production provided by the auxiliary heat production system.

The resulting share of the total heat demand covered by the heat pump is:

- Maximum forward water temperature 50ºC : 55%
- Maximum forward water temperature 55ºC : 75%
- Maximum forward water temperature 60ºC : 85%
- Maximum forward water temperature 70ºC : 88%.

From an energy production point of view, the heat pump should be able to heat the forward water up to 60ºC. If this desired temperature is in conflict with safe operation of the heat pump, it is highly recommended to reduce the temperature limit for the heat pump. This will normally be the case with ambient-air-based heat pumps in cold districts.

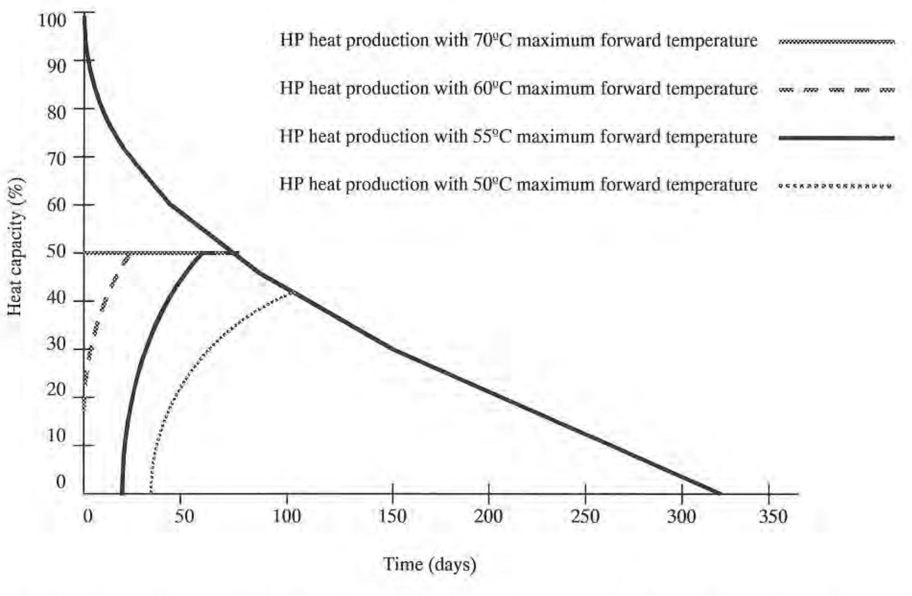

Figure 4.2 *Heat production from heat pumps with different maximum supply water temperatures.*

4.2.2 Problems with control of bivalent heat pump systems

The theoretical calculation of the share of the total heat demand contributed by the heat pump in Section 4.2.1 assumes that there is perfect control of the heat pump and the auxiliary heating system. The auxiliary system is normally a gas- or oil-fired boiler. In some countries such as Norway, electrically-heated boilers are also frequently used. The theoretical calculation assumes that the heat pump operates at 100% capacity before supplementary heat from the boiler is added, unless the temperature level exceeds the maximum temperature limit for the heat pump.

When retrofitting existing heating installations, however, there may be problems connected with the interaction between the heat pump and the auxiliary boiler. If the capacity control of the boiler is incorrect, or if it is regulated in steps, the boiler will occasionally add too much heat to the hydronic system. In the next round, this will lead to an increased return temperature from the heat distribution system to the heat pump, and the forward water temperature may exceed the permitted temperature limit. The heat pump will stop or reduce its capacity, and the heat pump's share of the total heat demand will decrease.

The best way to achieve optimal control of a bivalent heat pump installation is to use the same controller for both the heat pump and the auxiliary boiler. However, some heat pumps have their own integrated control systems, and are not designed to accept control signals from external controllers.

When hydronic heating systems are to be retrofitted with a heat pump installation, the heat pump must be installed in the return line before the existing boiler(s), see Figure 4.3. Special attention must be paid to the control system in order to achieve safe and efficient operation of the heat pump system.

4.2.3 Heating-only heat pump systems

The heating installation is controlled by an outdoor temperature compensation system which controls the setpoint of the supply water temperature. The heat pump will cover the base load, and it should, if possible, operate at full capacity before the supply heat from the oil-fired boiler is added. The peak-load boiler supplies the correct amount of additional heat by means of a valve system, as shown in Figure 4.3. If the heat distribution temperature exceeds the maximum permitted forward water temperature from the heat pump condenser, the heat pump will have its own safety control system, which will reduce the capacity to the accepted level, or the heat pump will be shut down.

The two valves for additional heat control may be replaced by a three-way valve. The oil-fired boiler normally operates at higher water temperatures than the heat distribution system, and it is of great importance that the heat from the boiler is not supplied in too large amounts, as this will lead to increased return temperature to the heat pump. If the heat pump is operating close to its high-temperature limits, it may be switched off.

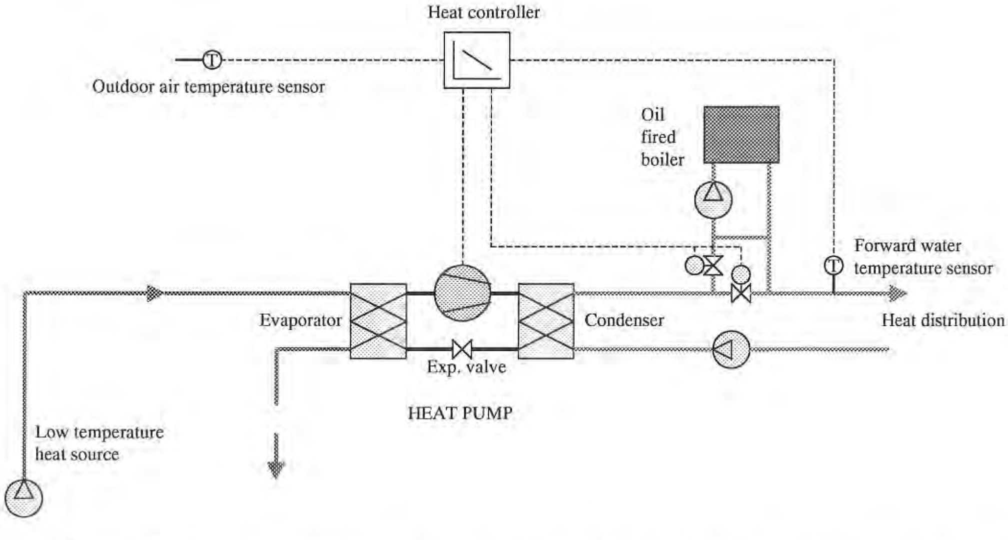

Figure 4.3 *Schematic piping diagram of a heat pump system operating with an auxiliary boiler, and their associated control equipment.*

4.2.4 Heat pump systems for combined heating and cooling

In the case of retrofitting an existing building in order to cover cooling demands, it could be very profitable to install a cooling installation which can also be used as a heat pump. In Figure 4.4, an example is shown of a schematic diagram for a heat pump system for combined heating and cooling.

The automatic control of the heat pump must differ between heating (winter) and cooling (summer) operation. Switching between these operating modes may be performed automatically, or manually by the operator, according to the outdoor air temperature or the calendar (date).

Cooling operation (Figure 4.4)
The cooling installation is controlled to keep the forward water temperature of the cooling distribution system at the desired level, which is often a constant temperature (5 – 10°C). The return cooling water is pre-cooled by heat exchange with seawater, and thereafter re-cooled to the desired temperature by the heat pump evaporator. The heat extracted by the heat pump is delivered to the heat distribution system, where a part of it is used for heating purposes, for example by preheating domestic hot water (DHW). The surplus heat is given off to the sea through a separate heat exchanger. The temperature level in the heat distribution system is controlled by a regulator controlling the three-way valve for excess heat.

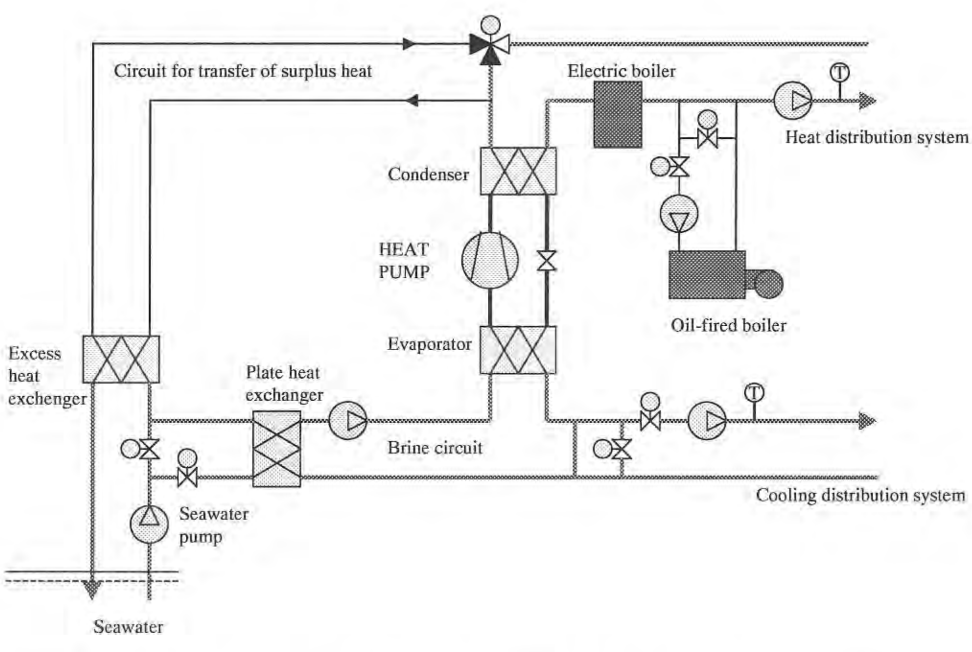

Figure 4.4 *Example of a heat pump system for both heating and cooling.*

Heating operation (Figure 4.4)
When the heating demand is greater than the available condenser capacity at cooling operation, the system is switched to heating mode. The heating installation is then controlled by an outdoor temperature compensation system as described for the heating-only heat pump system. The heat pump is able to cover the cooling demand also in heating operation. If the seawater temperature is much higher than the desired temperature level of the cooling distribution system, it may be possible to control the brine circuit temperature by means of control valves in the seawater line.

4.3 Heat pumps for high-temperature heat distribution systems

Before CFCs were banned, a number of heat pump working fluids were available for high-temperature applications. R-12 and R-500 were suitable working fluids for heat pumps in high-temperature hydronic systems, able to heat the water to about 70ºC. For higher-temperature industrial applications, R-114 and R-123 could satisfy heating demands up to 120ºC.

The HCFCs include a high-temperature working fluid, R-124, which could be a replacement for R-114. Also introduced were a number of R-22-based blends to be used as R-12 replacements in retrofitting existing heat pump installations. However, the HCFCs are now regulated by the Montreal Protocol, and are to be phased out.

About 1990, when the HFCs were commercially available, R-134a was introduced as the R-12 replacement working fluid. The two fluids have approximately the same pressure-temperature curves. Several heat pump manufacturers introduced standard R-134a heat pumps for water-heating up to more than 70ºC. However, a number of compressor breakdowns were soon reported, especially with semi-hermetic piston compressors with capacity control operating at part-load at high temperature lifts. As a result, the maximum recommended operating temperature limit was gradually decreased to 55-60ºC. However, with new compressors designed specifically for R-134a, the maximum operating temperature limit has increased to 60-65ºC. In larger units, R-134a is used up to 84ºC condensing temperature.

Currently, there are no commercially available heat pumps with environmentally-friendly halocarbons that can work with higher water supply temperatures than 60-65ºC. There is a new group in the experimental stage – the hydro-fluoro-ethers (HFEs) which have a maximum operating temperature above 100ºC. However, it is also possible to reach the required temperatures in many existing buildings by using heat pumps with natural working fluids.

4.3.1 Natural refrigerants as working fluids

In contrast to the HFCs, which fail in high-temperature applications, there are a number of natural working fluids which are well known as working fluids in heat pumps and refrigeration installations. The cheapest is water, which is used as a working fluid in high-temperature industrial heat pump systems. For space heating in buildings, the following natural fluids are available as heat pump working fluids:

1 Ammonia;
2 Hydrocarbons; and
3 Carbon dioxide.

4.3.1.1 Ammonia

Ammonia has rather high pressures on the condenser side when it is applied in heat pumps for higher temperatures. Conventional 25 bar equipment is not suitable. For applications at higher temperatures, 40 bar compressors have been designed, and supply water of 70ºC is possible. Such compressors are in extensive use in supercharged heat pumps connected to large refrigeration installations in the food industry in Scandinavia. The purpose of these heat pumps is normally hot water production, and in some cases space heating as well.

These 40 bar compressors may also be part of the solution for retrofit heat pumps. Figure 4.5 shows a schematic diagram of a two-stage heat pump in a district heating system.

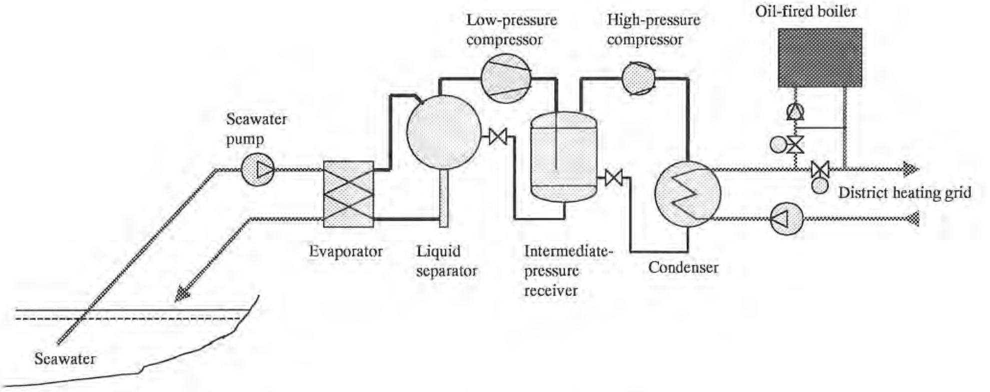

Figure 4.5 *Two-stage ammonia heat pump installation.*

Ammonia is toxic and flammable. In some cases this may cause problems in finding a suitable machinery room for ammonia heat pumps for retrofit in buildings. Using an ammonia heat pump as the main heat source in a district heating plant is an excellent solution, however, since the heat pump is normally located in a separate machinery room. In Norway, there are two small district heating systems with two-stage ammonia heat pumps in operation.

- At the main Bodø Air Force Base, an ammonia heat pump was installed in a district heating plant in 1992, in order to replace the oil-fired boilers for heating the buildings. The heat pump heating capacity is 2 MW, and the design heat distribution temperature is relatively high (80/65ºC). Seawater is used as the heat source.

- The Stjørdal district heating system is based on a two-stage ammonia heat pump with 1.3 MW heating capacity, using sewage water as a heat source. Parts of the city and the airport are heated by the bivalent heat pump system, which operates with 80/55ºC as design supply/return temperatures. The heat pump has been in operation since 1994.

These two heat pump plants have performed well. They are good examples of heat pumps using ammonia as working fluids which can operate at higher temperature levels and with higher efficiency than the traditional halocarbon systems.

The following information is taken from reference [14]:
In Switzerland, the initial phase of the development of a residential heat pump with ammonia as the refrigerant was completed in 1998. This research was implemented as one of the initiating projects for the development of a Swiss retrofit heat pump, see Section 4.3.2. Initial efforts focused on the performance of ammonia heat pumps compared to heat pumps with R-22, R-290 and R-407C. At low heat distribution temperatures, the ammonia heat pump was calculated to be about 10% more efficient. This number becomes lower for higher sink temperatures. Very low refrigerant content is sufficient when an indirect evaporator is used with a water/ethylene glycol mixture transporting the heat from the outdoor air heat exchanger, but this compromises the efficiency [15].

4.3.1.2 Hydrocarbons

Hydrocarbons are in extensive use as refrigerants for some applications, such as domestic refrigerators and small exhaust-air-source heat pumps, mainly in Europe. There are also several industrial heat pump applications with hydrocarbons as the working fluid [16].

The hydrocarbons butane and iso-butane may be used in high-temperature heat pumps for retrofit. These working fluids have a normal boiling point of -0.5°C and -11.7°C respectively. The critical temperatures are 152°C and 134.7°C, with corresponding critical pressures of 38 bar for butane and 36.4 bar for iso-butane. This means that a butane heat pump, for example, can warm water up to 100°C at a condensing pressure of 16 bar. Consequently, there are no practical temperature limit restrictions when using these hydrocarbons as working fluids for retrofit heat pumps.

The main problem with the use of hydrocarbons as working fluids is their flammability. When the heat pump is located within the building to be heated, it must normally be placed in a gas-tight container. Further, the air surrounding the heat pump must be evacuated continuously to avoid any possible build-up of an explosive mixture in the event of a hydrocarbon leak from the installation [16].

4.3.1.3 Carbon dioxide

The most striking properties of carbon dioxide (CO_2) are its high vapour pressure and low critical temperature. The critical temperature is 31.1ºC, and the corresponding saturation pressure is 73.7 bar. Due to the low critical temperature, heat pump systems for retrofit that reject heat at medium and high temperatures will have transcritical operation, i.e. the evaporation occurs below the critical pressure, and the heat is rejected as single-phase gas cooling (without condensation) above the critical pressure.

Figure 4.6 shows the principle of a simple CO_2 system designed for supercritical operation. The main components of the plant comprise a compressor, a gas cooler, an internal (suction gas) heat exchanger, an expansion valve, an evaporator and a receiver at the evaporator outlet [16].

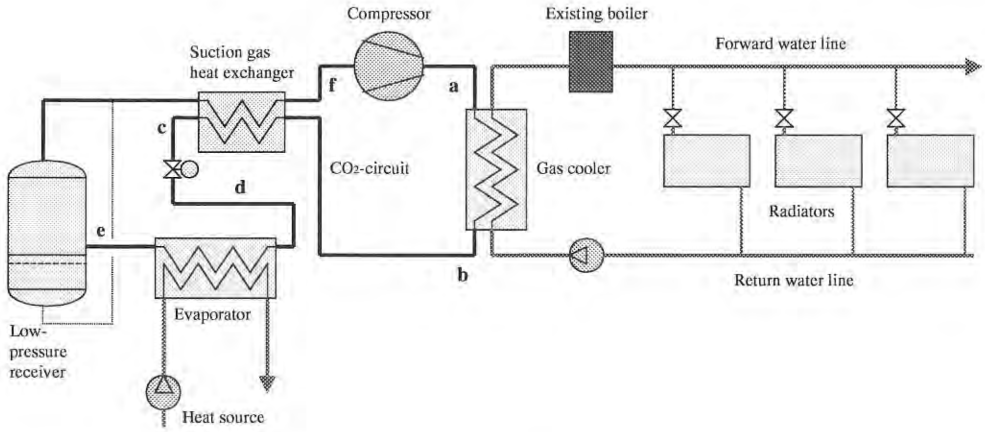

Figure 4.6 *Schematic diagram of a CO_2 heat pump in a hydronic distribution system.*

In transcritical CO_2 heat pumping systems, the supercritical high-side pressure is independent of temperature. Moreover, the pressure is not a direct result of a heat balance in the gas cooler, but of the momentary CO_2 charge on the high-pressure side of the system (i.e. number of CO_2 molecules and system volume). Both the refrigerating/heating capacity and the COP of the CO_2 systems will depend on the pressure level. Pressure control can be achieved by adjusting the opening of the expansion valve, thereby transferring the CO_2 charge between the high-pressure side of the system and the receiver. Reduced opening of the expansion valve means increased pressure, and the specific cooling and heating capacity will increase, as shown on the pressure-enthalpy diagram of the transcritical cycle in Figure 4.7.

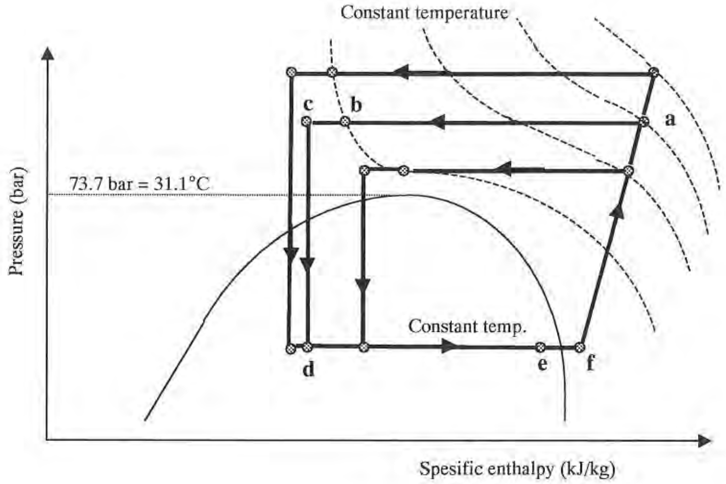

Figure 4.7 *Pressure-enthalpy diagram displaying alternative transcritical cycles [16].*

Increased pressure also means an increase in power consumption, and there is an optimum high-side pressure with regard to maximum COP [16]. This is due to the slope of the temperature lines in the pressure-enthalpy diagram above and near critical point.

From Figure 4.7 it appears that the CO_2 gas temperature after the gas cooler should be as low as possible in order to obtain high efficiency. In a high-temperature hydronic system with design temperatures of 70/50°C, the high-pressure CO_2 gas may be cooled to a temperature slightly above 50°C. Such temperature conditions mean very poor efficiency for a CO_2 heat pump process. At higher ambient temperatures, the hydronic temperature level decreases, and the efficiency of the CO_2 process improves.

In order to benefit from the large temperature glide offered by the supercritical gas cooler, a higher temperature difference between the inlet and outlet temperatures of the heating system can be achieved by decreasing the water flow in the hydronic system. Larger temperature differences between supply and return temperatures require special valves with a perfect setting, otherwise the system will not work.

A theoretical study of CO_2 heat pumps for retrofit in typical hydronic heating systems in western Europe shows how the energy efficiency can be improved considerably. A system originally designed for temperatures of 70/50°C was proposed modified by reducing the mass flow rate of water to obtain a 93/40°C system, which would give the same heat output using the existing radiator system. The SPF was then increased from 2.8 to 3.2. In addition, this system is able to supply domestic hot water (DHW) without any drop in the energy efficiency [17]. These characteristics of CO_2 heat pumps mean that they are highly suitable for retrofit applications where high supply temperatures are required.

4.3.2 Cycles adapted for retrofit application

The research and development programme for 2000 – 2003 of the Swiss Federal Office of Energy (SFOE) focuses on development of new heat pumps for the retrofit sector, and the improvement of the overall system (heat source, heat pump, distribution system and building). Information is taken from [14]. Several projects have elaborated the fundamental needs for a retrofit heat pump in Switzerland:

- Development and testing of new cycles for high efficiency and thermal output at the high temperature lifts customary in the retrofit market;
- Research on components with low liquid hold-up, which are also suitable for natural refrigerants;
- Development of new, more intelligent control concepts, with system diagnosis for high efficiency with low storage volume; and
- Development of safety systems for natural working media.

Figure 4.8 is a schematic diagram of a heat pump with a separate loop for condensate sub-cooling. A prototype was built and tested. R-407C was used as refrigerant. The auxiliary loop achieved about 5% higher COP values and 20% higher capacity than the conventional cycle. An improvement of around 10% may be expected when azeotropic mixtures or pure fluids are used instead of non-azeotropic R-407C. However, the higher complexity and the absence of suitable components for small heat pumps make the process more suitable for larger systems [18].

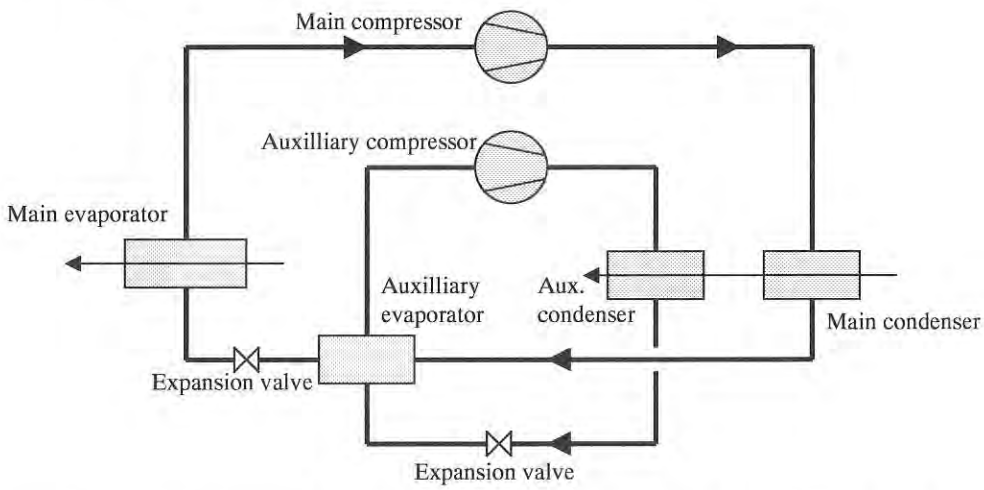

Figure 4.8 *Schematic diagram of a heat pump with a separate loop for condensate sub-cooling [14].*

Several heat pump concepts with compressor and vapour injection have been developed and tested in Switzerland [19, 20]. Figure 4.9 shows the concept of an air-to-water heat pump with intermediate suction [20]. This concept was built and tested with a prototype compressor with an intermediate suction opening which was adapted to the relatively large volume flow in heat pump operation. The intermediate suction results in a lower hot-gas temperature, and an improvement of the COP by up to 15% compared to a conventional model, at a source temperature of -7ºC and a sink temperature of 60ºC. The heating capacity is increased by about 30% at high temperature lifts. However, the compressor is not commercially available.

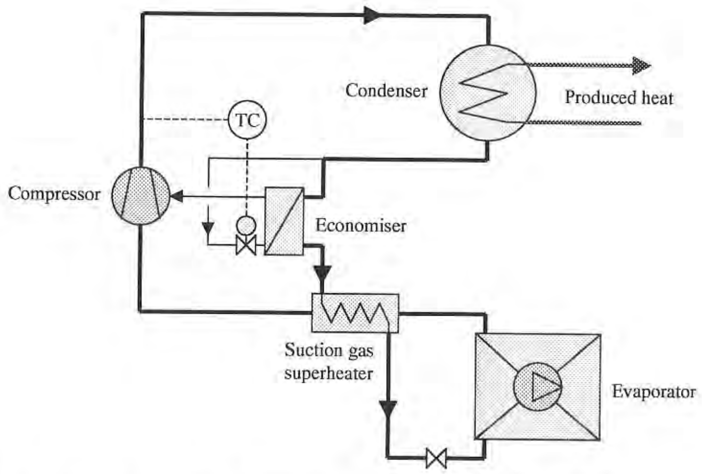

Figure 4.9 *Heat pump with high temperature lift, with suction gas superheater, intermediate pressure suction, and economiser [14].*

Figure 4.10 shows a schematic diagram of a two-stage heat pump, again developed for the retrofit market.

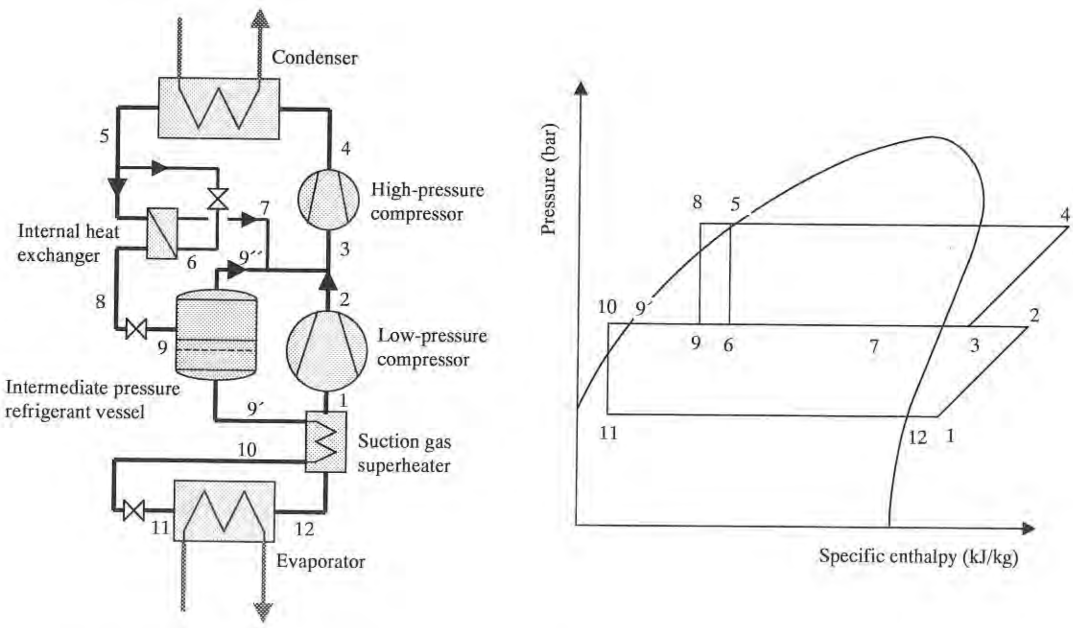

Figure 4.10 *Two-stage heat pump with two-phase intermediate injection [21].*

The performance of the heat pump in Figure 4.10 was tested at heat source temperatures between -12ºC and +12ºC, and a sink temperature of 50ºC. The COP at -12ºC is about 3.0 for both R-22 and R-407C. Phase two of the project concentrated on de-icing of the evaporator of the air-to-water heat pump. Three de-icing methods were evaluated: by reversing the cycle; by using the heat stored in the economiser vessel; and a hybrid process combining both. The last method caused lower reduction of the COP and lower reduction of the heating capacity. However, the performance of the heat pump deteriorated after several defrost cycles. Research to find the reasons for this is ongoing [21].

In 1998, SFOE initiated the competition "Swiss retrofit heat pump (SRHP)". Manufacturers were challenged to develop a monovalent heat pump for the Swiss retrofit market. The SRHP should:

- Achieve a higher seasonal performance factor than existing heat pumps, with a smaller storage volume;
- Permit efficient operation with ambient air as a heat source and supply temperatures up to 60°C;
- Where possible, use natural working fluids; and
- Be cheaper than present-day heat pumps, through modular construction and serial production.

One of the four proposals has been selected for field testing for the 2000 – 2001 heating period. The tests have shown very promising results, but also the possibility for some further improvements. Two more prototypes will therefore be built and field tested in the 2001 – 2002. A group of Swiss heat pump manufacturers is planning to introduce the SRHP on the market in 2002.

4.3.3 Absorption-type heat pump systems

Heat-driven heat pump systems can operate at higher temperatures than state-of-the-art, commercially available electric heat pumps. This makes them particularly interesting for the retrofit market. In some countries, where electricity is relatively expensive, a heat-driven heat pump can also be economically more attractive than an electrically-driven one.

Absorption heat pumps for retrofit have some major advantages over electric heat pumps. A heat source, such as an oil or gas burner is already integrated, and the heat pump can be used in a boiler mode if the operating conditions exceed the heat pump working limits. Another advantage is that absorption heat pumps extract only about half the ambient energy of an electric heat pump of the same capacity. This means that a ground collector can be proportionally smaller.

Like the electric heat pump systems, heat-driven heat pump systems have been known for a very long time, but further research and development work is needed to make them economically attractive for certain applications. Three different prototype installations are discussed below.

4.3.3.1 Diffusion absorption heat pump

For residential use, specifically in the retrofit market, a concept known as the Diffusion Absorption Heat Pump (DAHP) has been developed by Swiss Creatherm [22]. It has been sold to the German company Buderus, which is developing it further at its Dutch subsidiary company, Nefit Buderus. About 100 units have been field-tested in the Netherlands and Germany during the 1999 – 2000 heating season. The company intends to introduce the gas-fired diffusion-absorption heat pump into the market in 2001 [23]. Compared with a current high-efficiency boiler, the tests on the gas-fired heat pumps showed an average increase in performance of 20%. Another very promising development based on similar ideas is going on in Switzerland, and will be ready for field tests soon. Figure 4.11 shows a diagram.

The gas-fired DAHP has a heating capacity of 3.6 kW. A maximum of 1.4 kW of this generated heat is taken from the external source, whereas 2.5 kW can be added by the gas burner. The heat pump operates with a PER of more than 1.4. In the Netherlands, this is equivalent to a COP of 3.5 for an electric heat pump.

Another promising development based on similar ideas is going on in Switzerland and will be ready for field tests soon.

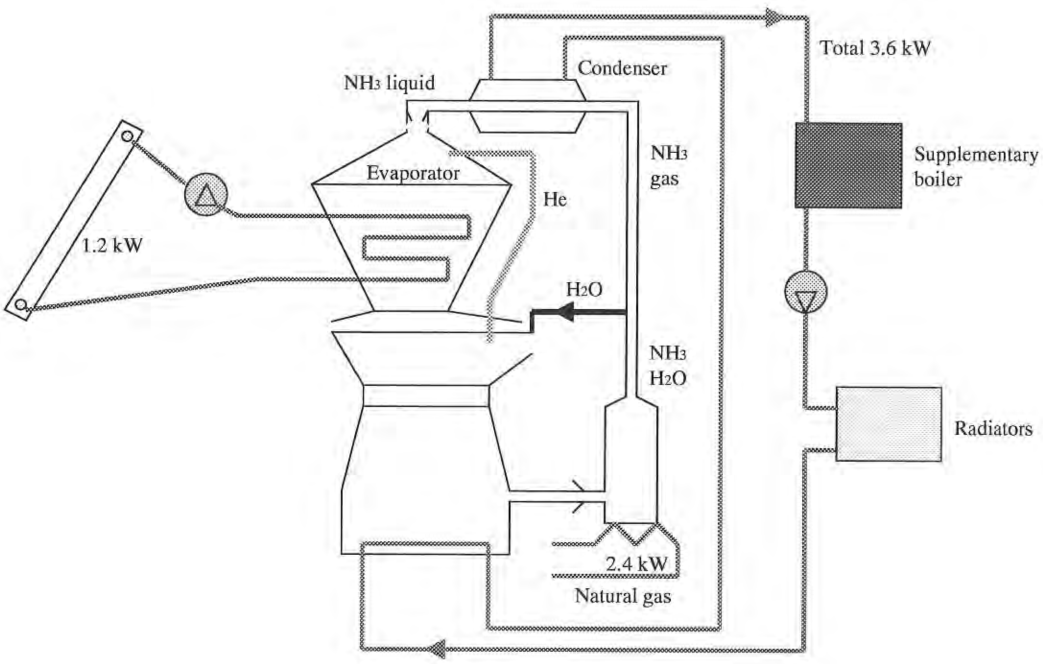

Figure 4.11 *Gas-fired diffusion-absorption heat pump*

4.3.3.2 Gas-fired absorption heat pump

The Austrian heat pump and solar technology company Heliotherm Wärmepumpen- und Solartechnik has developed an absorption heat pump (AHP) which is specially designed for the retrofitting of gas- and oil-fired boilers in one- and two-family houses. The AHP is driven by a gas or oil burner. It offers a maximum heat supply temperature of 50ºC in heat pump operation, and 70ºC in boiler mode. The capacity is 18 kW for heat pump operation, and 20 kW in boiler mode. In heat pump operation, it reaches a primary energy ratio (PER) of 1.4 at 50ºC heat supply temperature and a brine temperature of -5ºC, and a PER of 1.7 at 32ºC supply temperature and +8ºC brine temperature [24].

Heliotherm has developed the concept into a product suitable for the residential market. A brine system replaces the original air evaporator. The brine system allows utilisation of various heat sources: ground, air, water or low-temperature heat from solar collectors. Plate heat exchangers have replaced the shell-and-tube heat exchangers of the original, to achieve a compact system (70x95x140 cm). A control system for smooth switching between heat pump and boiler mode was also developed. The heat pump is illustrated in Figure 4.12.

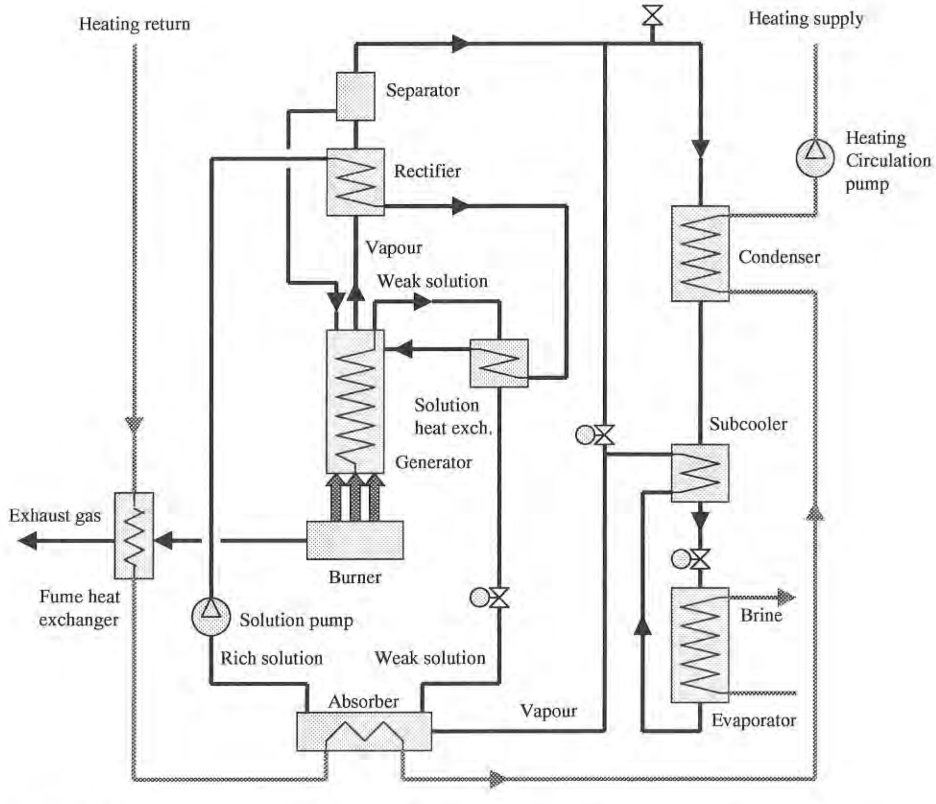

Figure 4.12 *Schematic diagram of Heliotherm's absorption heat pump.*

At the end of 1996, the first AHP prototype was installed at a nursery school in Amaliendorf in Lower Austria. In the 2000 – 2001 heating season, a further developed prototype was being tested intensively. A large field test was planned for 2001 – 2002.

4.3.3.3 Absorption/compression heat pumps

In Norway, a project was started in 1995 to develop a hybrid heat pump for high-temperature applications. The compression absorption system has been known for more than 100 years. It has been a focus for further development during the last 50 years, with special emphasis on energy saving. The working pair ammonia/water offers a very good possibility for high-temperature applications of industrial heat pumps due to the possibility of adjustment of the head pressure by the composition of the fluid, as well as improvement of the COP by employing the temperature glides in the low- and high-temperature heat exchangers. A number of experimental installations have been built, and a COP improvement of up to 50% compared with a pure fluid compression system has been reported [25].

Ammonia has a condensing temperature of 49ºC at 20 bar, while 4% water content (by weight) in the ammonia gas results in a corresponding temperature of 110ºC. Heat can therefore be delivered at remarkably high temperature using a standard compressor [26].

As the mixture has two components, the heat exchange occurs at a gliding temperature, both in the absorber and the desorber. By changing the share of both components, the temperature glide of the working fluid can be adapted to the temperature glide of the heat source and the heat sink.

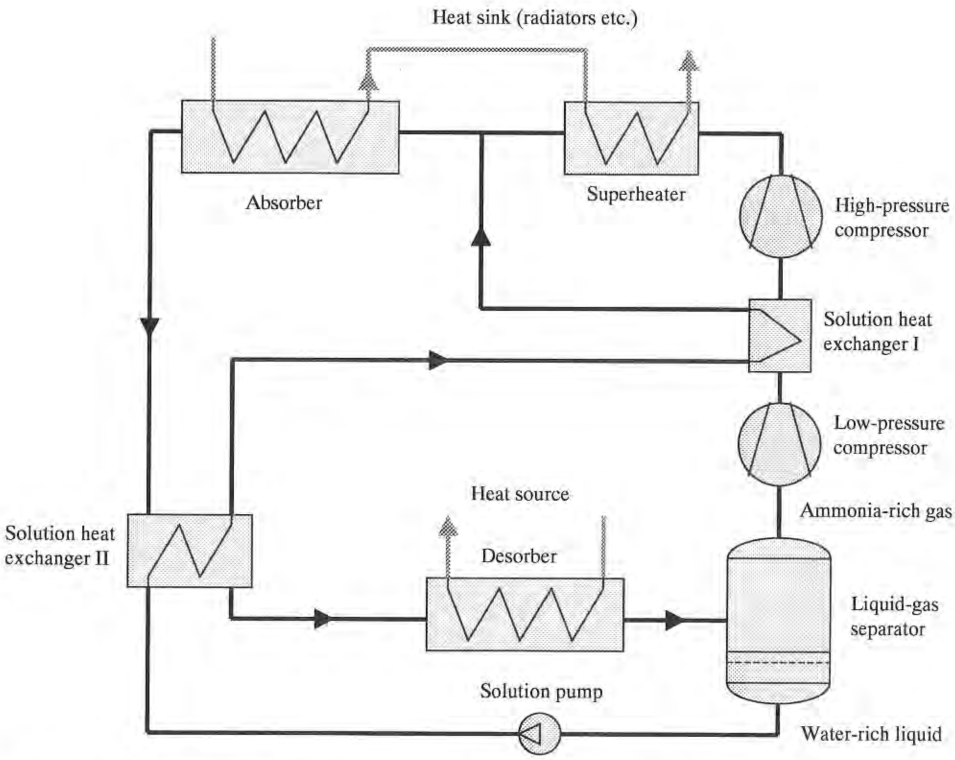

Figure 4.13 *Absorption/compression heat pump flow chart.*

The Institute of Energy technology (IFE) in Norway has built a 60 kW pilot absorption/compression heat pump, Figure 4.13. The heat pump system uses a two-stage, oil-lubricated reciprocating compressor. It is equipped with standard plate-type heat exchangers for the absorption (heat delivery) and desorption (heat recovery) processes, as well for internal heat recovery.

In the phase-change processes, ammonia is absorbed and desorbed via the ammonia/water liquid mixture. The concentration variation is a key factor in the heat pump operation. The main difference between this and a conventional vapour compression system is that the pressure-raising process is separated into two parts, one process for ammonia-rich gas and another for water-rich liquid.

Since this heat pump is designed for high-temperature applications, it is primarily of interest in retrofit situations.

4.4 Potential retrofit applications

The profitability of retrofit heat pump installations will vary widely, depending on the factors discussed in Section 4.3 above. One heating function which is attractive for heat pumps is domestic hot water (DHW) production, due to the long operating time of the heat pump.

4.4.1 Domestic heat pump water heaters

About 15-20% of the energy consumption in residential and commercial buildings is used to heat tapwater. However, the relative importance of the energy consumption for hot water heating is growing, as the demand for space heating continues to fall due to improved insulation standards and new building designs.

In new buildings, optimised, integrated heat pump systems for space heating, space cooling and DHW heating seem to be the energy system with a minimum energy consumption. In many cases, it is much easier to incorporate a heat pump for retrofit of the hot tapwater system than to retrofit the overall heating system of the building.

4.4.1.1 CO_2 heat pump for DHW production

A newly-developed CO_2 heat pump water heater offers high-temperature heating with a considerable reduction of energy consumption. The process for hot water heating is shown in the T – S diagram and the h – log p diagrams in Figure 4.14. It is of great importance that the CO_2 gas temperature after the gas cooler is as low as possible. If cold water of 10 or 15ºC enters the gas cooler in order to be heated to the desired hot water temperature, the CO_2 gas temperature may easily be cooled down to 20ºC as shown in the T-S diagram on the left hand side of Figure 4.14. The h – log p diagram in Figure 4.14 shows that the energy efficiency of the heat pump process increases considerably when the hot gas is cooled down to 20ºC compared with 40ºC end cooling for a space heating process.

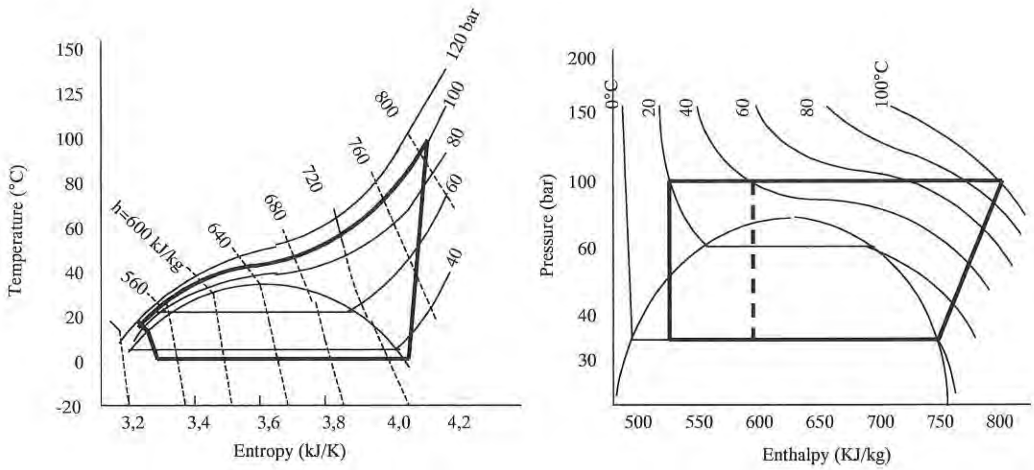

Figure 4.14 *Transcritical CO_2 process in the T – s diagram and the h – log p – diagram.*

Figure 4.15 shows the principle of a piping diagram of the CO_2 heat pump water heater with evaporator for heat recovery from the low-temperature heat source, and gas cooler for hot water production. The gas temperature after the compressor depends on the pressure of compression, which must be controlled to ensure that the CO_2 gas temperature at all points is higher than the water in the gas cooler. The desired hot water temperature is controlled by means of the throttling valve in front of the evaporator.

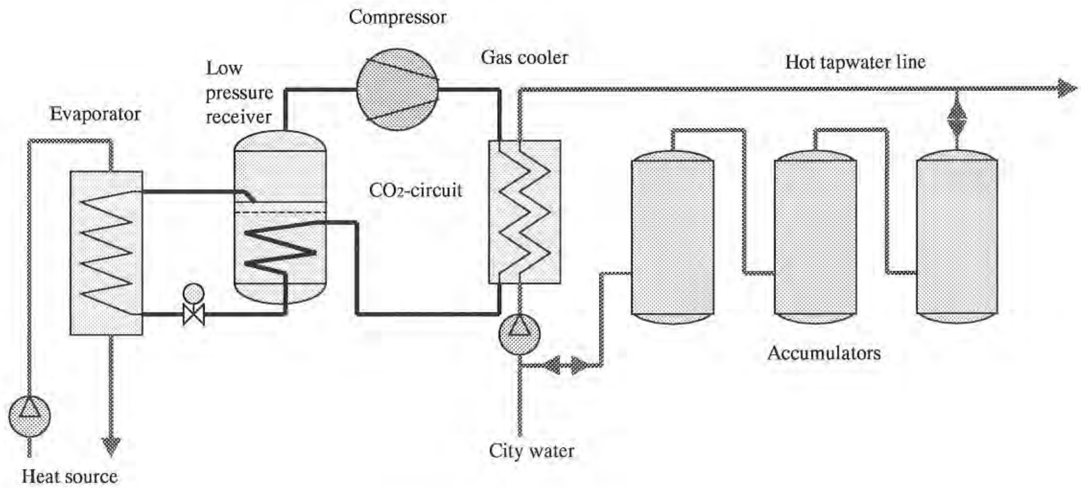

Figure 4.15 *Schematic piping diagram of a CO_2 heat pump water heater.*

The compressor of the CO_2 heat pump water heater has a swept volume of approximately 10% compared with the compressor of an R-134a heat pump for hot water production. The efficiency is also considerably higher for the CO_2 heat pump. Figure 4.16 shows the COP of the CO_2 heat pump as a function of the water temperature in and out of the gas cooler.

The COP in Figure 4.16 is based on theoretical calculations, and the calculated efficiency is in good agreement with measurements on a prototype installation at [27]. It is assumed that the CO_2 gas is cooled to a temperature which is 5ºC higher than the city water entering the gas cooler.

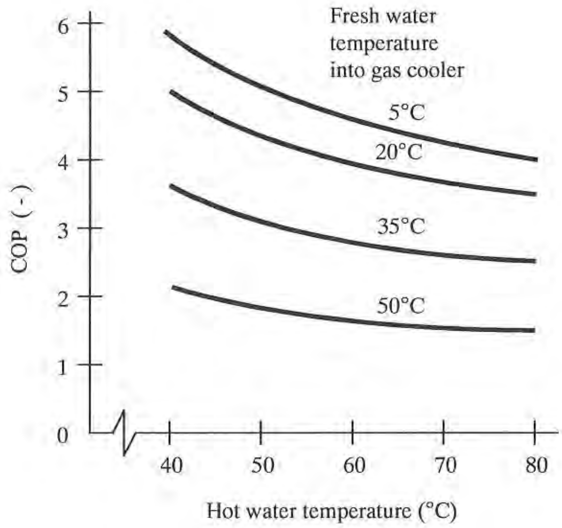

Figure 4.16 *COP of the CO_2 heat pump water heater as a function of the water temperature in and out of the gas cooler.*

The prototype CO_2 heat pump water heater installation at SINTEF in Norway has a heating capacity of approximately 50 kW, which may be a convenient size for a sports centre or a health institution. In Japan, Tokyo Electric Power Co. (TEPCO) has jointly with Denso Corp. been developing a residential CO_2 heat pump water heater [28]. The new water heater is intended to meet demands for residential hot water supply, which in Japan accounts for about 35% of energy consumption in residences.

Unlike HFC heat pump water heaters which can supply hot water of 60°C maximum, the CO_2 working fluid can supply hot water in the range of 60 to 90°C, even in very cold districts where ambient temperature drops to -20°C. Moreover, since CO_2 has superior heat transfer properties, the heat pump unit can be compactly designed, thus allowing freer choice of installation area.

4.4.2 Long operating hours

Heating demand varies significantly for different types of buildings, depending on the required indoor temperature, ventilation losses and demand for DHW. In new residential buildings, there is a demand for both DHW and ventilation air, which means a continuous heating demand – at least for hot water – and good conditions for heat pump installations. However, hospitals, nurseries and old peoples' homes have a comparatively higher demand, because of higher indoor temperature requirements and ventilation demands. In other types of buildings such as offices and schools etc., the ventilation system is normally switched off at night and weekends, or it is run at lowered fan capacity. The possibility of achieving a profitable heat pump system in a school building is therefore less than in hospitals, nurseries and old peoples' homes.

The county of Oppland in south-central Norway owns and manages several schools and hospitals. The county has investigated the possibilities of energy conservation in its buildings by retrofitting heat pumps. Table 4.2 shows a survey of the heating installations in a number of the actual buildings.

Some 80% of the buildings belonging to the Oppland County are equipped with hydronic systems for heat distribution. This is quite a high percentage for Norwegian conditions, and it is a benefit in relation to retrofitting with heat pumps. On the other hand, the existing hydronic systems are high-temperature distribution systems, which means unfavourable operating conditions for the heat pumps.

As shown in Table 4.2, the average specific heat demand is much higher in health institutions than in school buildings. At the same temperatures, the operating time for the heating installation is much higher for a health institution than for a school building, which favours heat pump installations in the former.

Table 4.2 *Survey of heating installations in Oppland County buildings in Norway.*

Building	Heated floor area (m^2)	Heating system			Design forward/ return temperatures (ºC/ºC)	Specific heating demand (kWh/m^2year)	
		Hydr.	Electr. + hydr.[1]	Electr.		Per building	Average values
Schools							
Herleid	12,450			X			
Otta	7,000	X			80/60	76	
Vinstra	12,780	X			80/60	132	
Gausdal	4,280		X				
Mesna	4,850			X			
Dokka	8,930	X				110	94
Raufoss	7,790			X			
Roa	4,820			X			
Ringebu	4,100	X			80/60	151	
Vargstad	11,560		X				
Klones	1,970	X				96	
Health Institutions							
Aurdal	3,200	X			80/60	154	
Kløverhagen	3,300	X			80/60	189	
Blåkors Eina	9,350	X				167	169
Kringsjåtunet	1,530	X				164	
Seljelia	1,360	X			70/50	152	
Gjøvik	46,460	X			80/60		
Lillehammer	56,060	X			80/60	185	

[1]Hydronic for heating the ventilation air, electric for compensating transmission losses

Figure 4.17 shows the heating load duration curves for three different hydronic systems:

- Hydronic system in health institutions;
- Hydronic system in school buildings; and
- Hydronic system for ventilation air heating only in school buildings.

The heating load duration curves are based on the average values of the specific heat consumption in Table 4.2, provided that the heating system covers the heating demand up to 15ºC ambient temperature. The ventilation installation operates 10 hours per day, five days a week. The heat pump is designed to cover 50% of the net heating load at design outdoor temperature for heating and ventilation of the different heating systems.

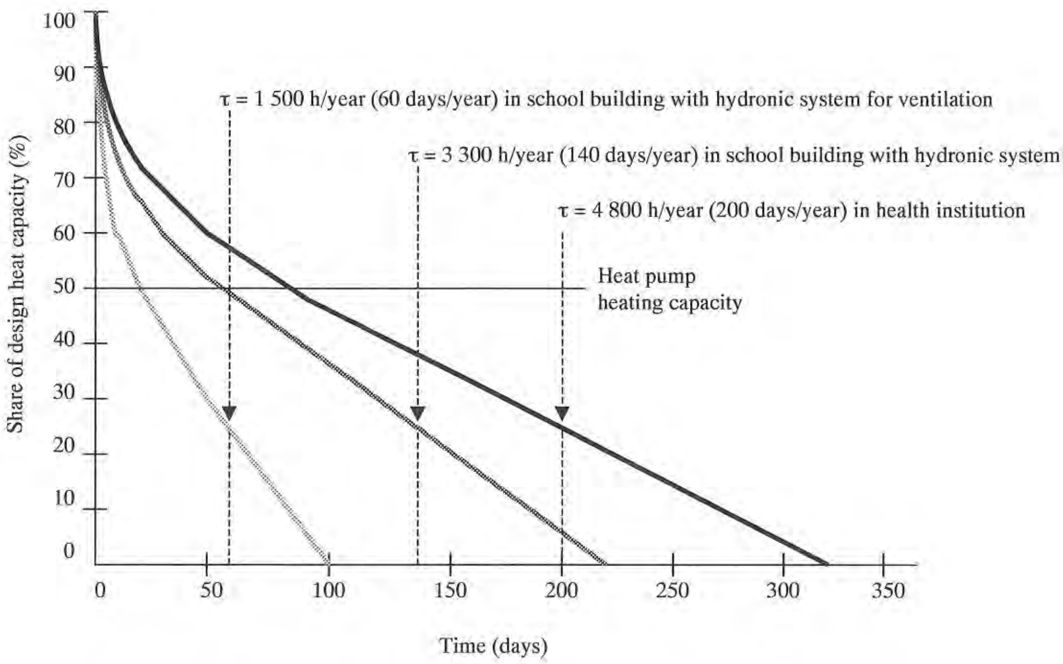

Figure 4.17 *Heating load duration curves for three different heating installations.*

Under these circumstances a heat pump installation in a health institution has 45% longer operating time than a heat pump in a school building, and it is therefore a much more profitable installation. A retrofit heat pump connected to a hydronic system for ventilation only in school buildings where the ventilation is switched off during nights and weekends, will have very short operation time, and poor resultant profitability.

4.5 Ductless air-to-air heat pumps

Of the estimated 100 million heat pumps installed throughout the world, about 75% by number are of the single-room, air-to-air heat pump type. For offices, multi-split heat pumps are popular. Both single-room and multi-split heat pumps are ductless systems. They are especially suitable for retrofit applications because they do not require a distribution system. The main markets for single-room and multi-split heat pumps are in Japan and China.

4.5.1 Single-room heat pumps

Though the main markets for single-room heat pumps are in Asia, air-to-air heat pump split units are increasingly being installed in Europe as well. In Norway, for example, 60% of the residences are single-family houses, and the traditional heating system is electric resistance heaters. Installing an air-to-air heat pump requires much lower investment than retrofitting the building with a heat pump and a hydronic heat distribution system.

Many single-family houses in Scandinavia have an open-plan layout, without walls between some of the rooms. As a result, an air-to-air heat pump with a centrally placed indoor heating unit (Figure 4.18) can cover a considerable part of the heating demand of the residence. The existing electric resistance heaters will provide supplementary heating. This combined heating system may be simply controlled by setting the heat pump thermostat at two or three degrees higher room temperature than the room thermostats for the existing radiators.

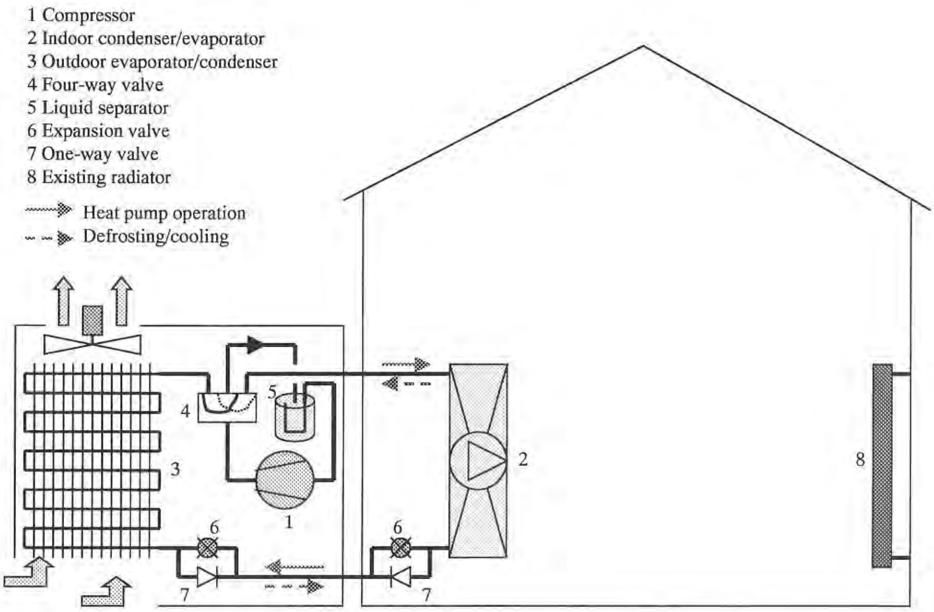

Figure 4.18 *Principle of an air-to-air heat pump system in an existing residence.*

In cold climates, the outdoor evaporator unit needs frequent defrosting. The defrosting operation is typically performed by a four-way valve reversing the refrigerant circuit for a short time. During defrosting, the indoor unit is working as an evaporator, and the outdoor heat exchanger works as a condenser until the ice is removed from the surface of the heat exchanger. This operating mode is also used for cooling the residence during summer. In warm climates, these room air conditioners are mainly installed for cooling purposes.

Some new split air conditioners do not reverse the cycle due to loss of comfort. At least one system uses a storage mass within the compressor shell as the heat source for defrosting.

4.5.2 Multi-split heat pumps

The multi-split heat pump system (Figure 4.19) is an air conditioning system specific to Japan, and is gaining a considerable market share [29]. The advantages for retrofitting are similar to single-room heat pumps: no separate distribution system is necessary. The refrigerant pipes are thin, and their installation through the walls of the building is relatively easy.

The multi-split heat pump packaged system is a high-efficiency, complete heat recovery system that automatically selects cooling/heating operation according to the heat load, which differs for each room throughout the year. Furthermore, the system makes effective use of waste heat when cooling or heating. This is achieved by the addition of a gas suction pipe to the existing liquid and gas discharge piping of the refrigeration system. The simultaneous availability of both cooling and heating functions is achieved through the selection of either the gas discharge or the gas suction pipe, depending on the ambient temperature and the temperature setting. The correct capacity of the cooling and heating are achieved by means of the collection and delivery of the correct amounts of refrigerant, which is performed by capacity control of the indoor unit heat exchanger and of the outdoor compressor and heat exchanger. Moreover, perfect control of the thermal balance is achieved by the use of inverter and fan speed adjustment controls, which in turn permit stable and efficient control in response to independent selection of cooling or heating mode for each indoor unit.

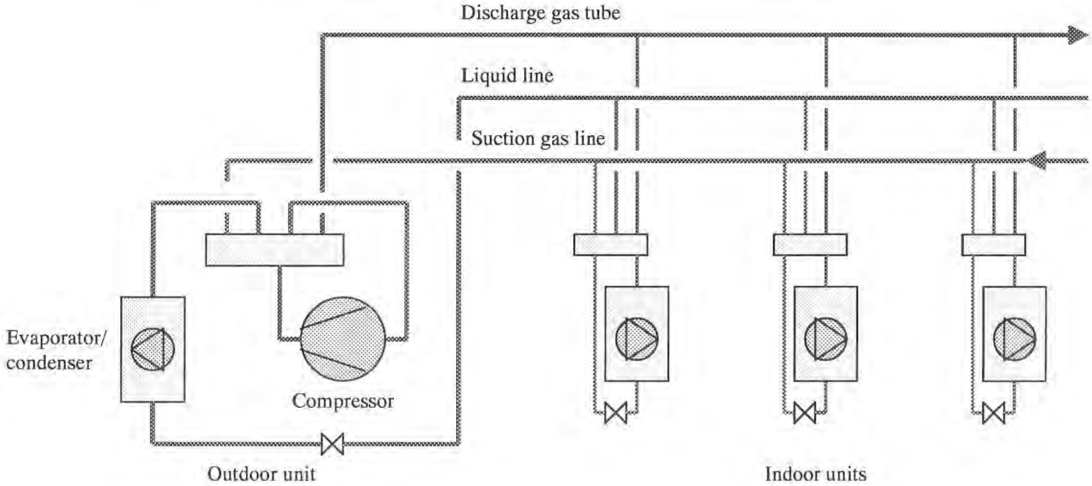

Figure 4.19 *Multi-split heat pump system for heating and cooling.*

By using the nearest unit to meet all local air conditioning requirements, rather than setting up separate cooling/heating and year-round cooling systems, it has been possible to reduce total facility capacity by some 10% to 20% from that of a conventional system. This complete recovery system operates by selecting the mode with smaller load during the course of simultaneous heating and cooling operations, and then using the refrigerant to transmit heat from the mode which is bearing the lower load to the mode which is bearing the higher load. In this way, it is possible in winter, for example, to use the waste heat from one room cooling operation to heat the remaining office space. A highly effective use of energy is thus achieved.

5 Examples of heat pumps for retrofit

This chapter presents examples of three major retrofit projects in Norway, where the practice of retrofitting heat pumps is furthest developed in Europe.

5.1 Two-step district heating and cooling at the University of Bergen

With conventional district heating, the heat distribution temperature must be sufficient to meet the needs of the building with the highest temperature requirements. This requires an expensive piping system for the transport of hot water, and when heat pump technology is used, it severely limits the achievable efficiency. A much better way is to deliver the heat in two steps, with heat distributed at a much lower temperature, and then upgraded to the temperature required for each application. This innovative approach is now being applied at the University of Bergen, Norway [31].

Figure 5.1 shows a schematic piping diagram for the heat pump system.

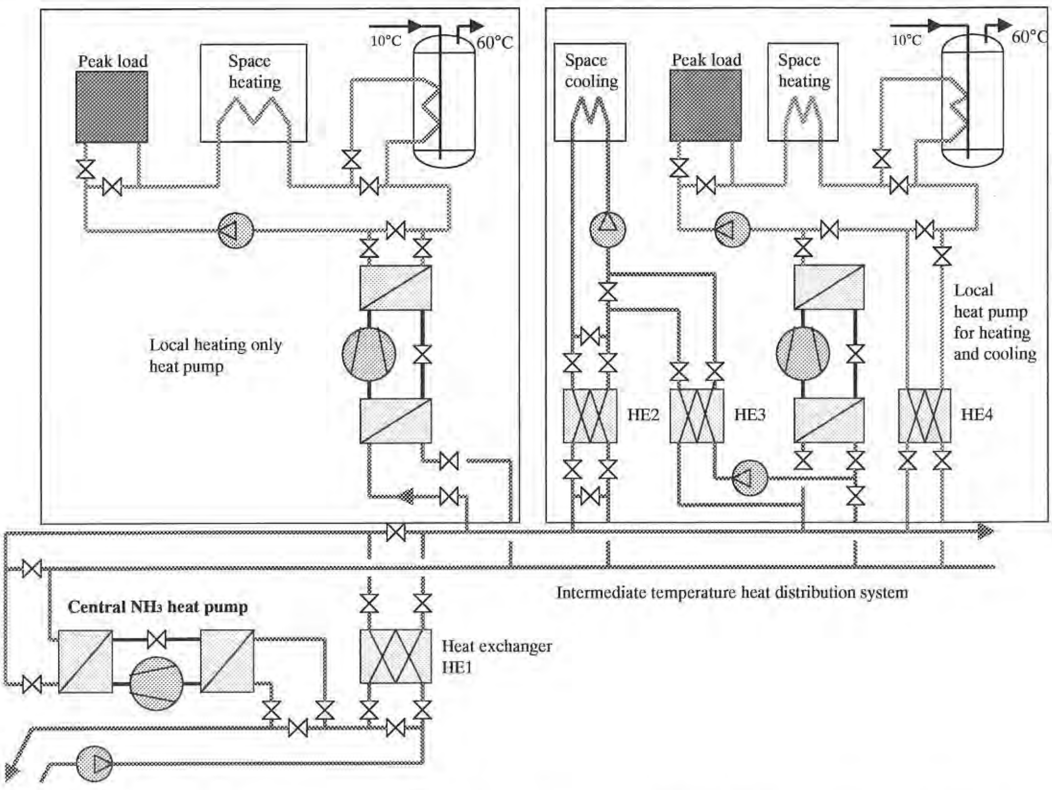

Figure 5.1 *Two-stage heat pump system with distribution at intermediate temperature at the University of Bergen, Norway.*

A central seawater heat pump unit supplies an intermediate heat distribution system which circulates water at an intermediate temperature. This water serves as the heat source or heat sink for several local heat pumps, which provide heating or cooling in individual buildings or groups of buildings. The system was chosen after a comprehensive technical and economic evaluation.

The university buildings vary widely as regards application area, year of construction, standard of thermal insulation, and desired comfort level, as well as heating and cooling requirements and heat distribution temperatures during the year. Low-temperature heating systems are installed in most of the buildings, but a few buildings are equipped with high-temperature heating systems. Therefore, the required distribution temperatures range from 55°C to 80°C.

The two-step system is well-suited to meet such wide variations in supply temperatures. Since heat is always provided at a minimum temperature level in the buildings, the heat pump system uses less primary energy, and obtains a higher SPF than a conventional district heating system with heat pump.

5.1.1 Upgrading heat from seawater

The central heat pump unit at Bergen is located in the new Faculty of Law building, situated on a hill near a fjord. Seawater at 30 metres depth is used as a heat source for the heat pump, and for space cooling in the building. The seawater temperature is relatively high, and stable during the year, with a minimum of 6°C in March and a maximum of 12°C in October. The central heat pump supplies the intermediate temperature heat distribution network at around 25°C. In contrast to conventional district heating and cooling systems, a simple pipeline system is used for heat distribution, in this case by supplying water of intermediate temperature between the central heat pump and the local heat pumps. Non-insulated plastic pipelines (for 16 bar maximum pressure) are placed in shallow ditches and covered with insulating filler (pumice-stone and gravel). This inexpensive distribution system offers many inherent advantages, although for this prototype project the benefits are not so significant since the buildings of the campus are located within a relatively small area.

The intermediate-temperature heat distribution system is designed for a relatively low temperature difference of 5°C. When more buildings are connected to the heat pump system, the transport capacity of the pipelines can easily be doubled by increasing the temperature difference to 10°C.

5.1.2 Supplying cooling

During long periods of the year, ventilation is sufficient to cover the entire space cooling demand in the buildings. When active cooling is needed, the central heat pump is switched off. At low cooling loads, heat exchanger HE2 transfers heat from the cooling distribution system to the intermediate heat distribution system, as long as there is a positive temperature difference. At higher cooling loads, the local heat pump is manually switched to cooling mode. The heat pump extracts heat from the heat exchanger HE3, and the cooling distribution system is used as a heat source for the heat pump. The compressor capacity is then controlled by the temperature requirement in the cooling distribution system. If the condenser heat exceeds the space heating and hot water demand in the building, excess heat is given off to the intermediate-temperature heat distribution system through the heat exchanger HE4.

5.1.3 Status of the retrofit heat pump project in Bergen

The heat pump system at the University of Bergen is designed to cover the heating and cooling demands of both new and existing buildings. The flexibility of the intermediate-temperature district heating grid makes it suitable for gradual development of the heating and cooling system.

In the original plans, the heat pump system should support eight university buildings with heating and cooling. The total heating load at design conditions was estimated at 3.4 MW, with an annual heating demand of 5.3 GWh. The maximum cooling load was to be 1.5 MW, and the annual space cooling demand would be about 0.6 GWH, i.e. about 15% of the annual heating demand.

The first part of this prototype system was completed in the spring of 1995. It included only the central heat pump system and a heat pump for the Faculty of Law building. During the following two years, three new local heat pumps were installed. In the autumn of 2000, the heat pump system comprised the primary seawater-based heat pump, and six local heat pumps.

The central heat pump is a 25 bar single-stage ammonia unit, equipped with a 16-cylinder reciprocating compressor, a two-speed electric motor, a titanium twin-plate heat exchanger as the evaporator and a standard twin-plate heat exchanger as the condenser. The heating capacity is 1,200 kW under the design conditions of 25°C outlet water temperature from the condenser and 6°C seawater temperature. The heating capacity equals the total evaporator capacity of the local heat pumps. If a higher capacity is needed in the future, two more units can be installed in the machinery room.

The six local heat pump installations have a total heating capacity of 1,900 kW, and the corresponding cooling capacity at 25ºC intermediate temperature level is 1,500 kW. This is higher than the primary heat pump capacity. Therefore, a new primary heat pump is to be installed in the near future.

5.2 Retrofit heat pump at Bussbygg AS

Bussbygg AS is a manufacturing company near the city of Molde in western Norway. The company produces insulated cabins for truck boxes. The corporate premises have a total floor area of approximately 10,800 m^2, requiring a considerable heating demand for the production hall and the painting and drying rooms, as well as for the administration building. The production hall was built with a floor heating system, with a combination of electric boilers and oil-fired boilers as the energy production plant.

In the manufacturing hall, there is a glue press which alternates between heating and cooling processes several times a day. In order to cover the cooling demand, a plastic tube seawater collector was installed in 1995.

The seawater collector consist of 16 parallel coupled tubes with a diameter of 40 mm and a length of 250 m each, i.e. a total length of 4,000 metres. The building is located 250 metres from the sea, and the collector is coupled to the production hall through 140 mm diameter plastic tubing as forward and return lines.

The building site at Bussbygg was prepared several years ago for a heat pump installation. Approximately 6,000 m^2 of the manufacturing halls and offices are heated by floor heating systems, and the seawater collector was originally designed to be the heat source for a heat pump. When the seawater cooling system was built in 1995, however, the heat pump installation was postponed for economic reasons. But in 2000, the heat pump plans were implemented because the energy cost for heating was increasing, and the indoor climate required cooling in summer.

Figure 5.2 shows a schematic diagram of the heat pump system, which is used both for heating and cooling. The heat pump installation is designed for cooling the glue press, and for cooling the floor heating system as well as the ventilation air in the large manufacturing hall. The condenser heat production is used for low-temperature floor heating.

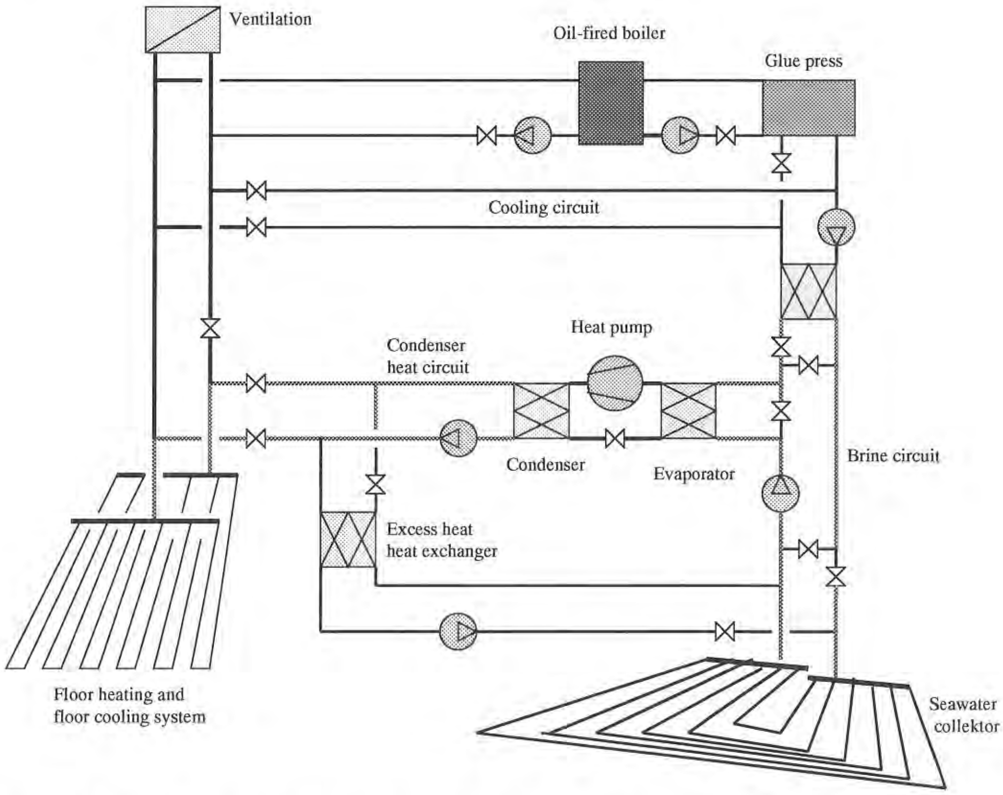

Figure 5.2 *Principle of the seawater-based heat pump for heating and cooling at Bussbygg AS, Norway.*

The heat pump is equipped with a semi-hermetic monoscrew compressor, and the working fluid is R-134a. Heating capacity is 190 kW at 0°C brine temperature leaving the evaporator, and 35°C water temperature leaving the condenser. At the design temperatures, the COP is 4.7.

5.3 Heat pump installation at Toyota, Drammen

The importing firm of Toyota cars in Norway has its main building in the city of Drammen, in the south-eastern part of Norway. The buildings include a 10,700 m^2 storehouse, and an administration building with 6,000 m^2 floor area. Up to 1999, the buildings were heated by a hydronic system with an electric and an oil-fired boiler. The heat distribution system consists of heat exchangers in the ventilation system in the office building, and a hydronic roof heating system in the storage rooms.

The radiant roof heating system in the store house, with a maximum heating demand of approximately 500 kW, requires the highest hydronic temperatures, while the ventilation heat exchangers are designed for lower hydronic temperatures. The forward water temperature to the roof radiation system is 80°C at design condition, and the return temperature from the roof radiation system is 60°C, which is forwarded to the heat exchangers in the ventilation system. The return temperature to the heating centre is 45°C at design conditions.

The office building was fitted with several small refrigeration plants with direct expansion evaporators in the ventilation systems. The large storehouse was not equipped with cooling facilities, and on hot summer days, the indoor air temperature became quite high.

Toyota puts a lot of effort into reducing energy consumption and pollution from its cars, and the same applies to its building sites worldwide. It is also recognised that investment in a good air-conditioned indoor climate is profitable. As a result, it was decided to build a heat pump for heating and cooling of the Toyota building in Drammen.

In the spring of 2000, a seawater-based heat pump was installed for heating and cooling of the buildings. Seawater at 30 metres depth is used as a heat source for the heat pump, and for space cooling in the buildings. The seawater temperature is relatively high and stable during the year, with a minimum of 6°C in March and a maximum of 9°C in October.

Figure 5.3 shows a schematic diagram of the heat pump system. The heat pump is connected to the seawater through a titanium plate heat exchanger and a brine circuit. The brine transports heating or cooling from the seawater to the cooling distribution system and to the heat pump.

The cooling coils in the store house roof must operate at higher cooling temperatures than 14°C to avoid condensation. They are therefore connected to the seawater system through a natural cooling heat exchanger. The cooling heat exchangers in the ventilation systems require 7ºC forward water temperature at design conditions. The brine circuit (cooling water) is therefore pre-cooled by the seawater and post-cooled by the heat pump before entering the heat exchangers.

The heating capacity of the heat pump is 280 kW at 0°C brine temperature leaving the evaporator and 55°C water temperature leaving the condenser, and the working fluid is R-134a. The maximum heat demand in daytime at design outdoor temperature (-21ºC) is 970 kW, and the temperature distribution in the bivalent heat pump system is as shown in Figure 5.3. During summer, the heat pump is operating to cool the brine circuit forward water to the cooling distribution system to 7ºC, and the surplus heat is given off to the sea through the excess heat exchanger. In summer operation, the temperature level in the heat distribution system is controlled to a maximum of 35ºC by a regulator controlling the three-way valve for excess heat.

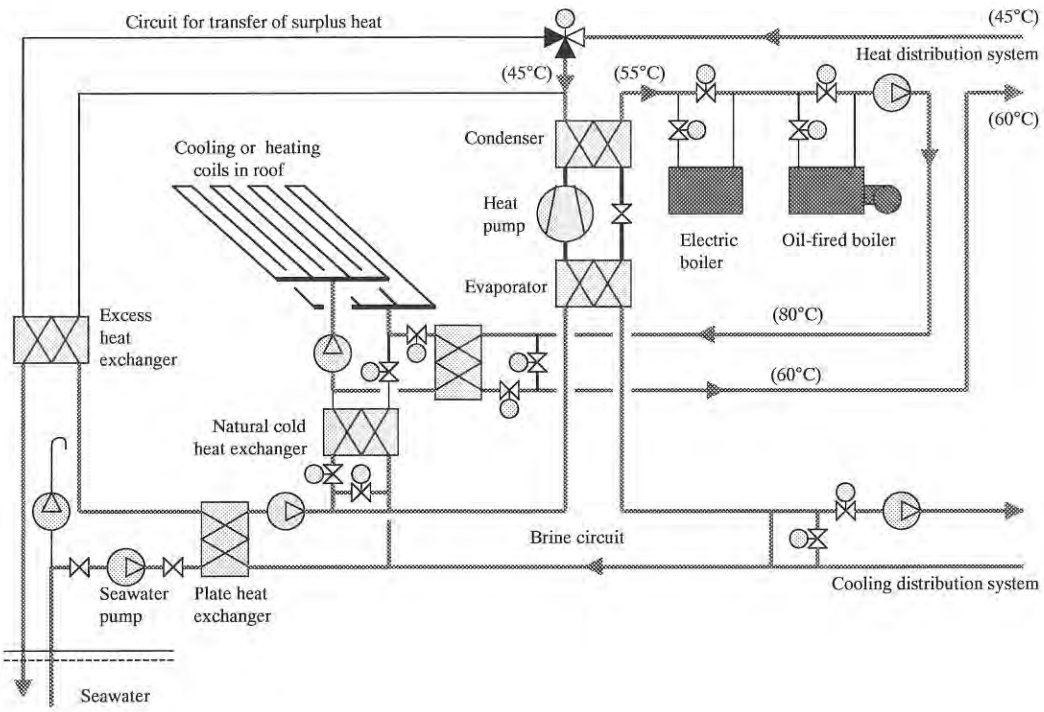

Figure 5.3 *Principle of the seawater-based heat pump for heating and cooling at Toyota, Drammen.*

6 Conclusions

The market for retrofit heat pumps has the potential to grow to about three times the size of the market for heat pumps in new buildings. However, in many countries, the market prospects of heat pumps for retrofitting existing heating systems in buildings are worse than those of heat pumps for new buildings. Notable exceptions are Japan and Norway (residential applications), where air-to-air room-type heat pumps are popular for retrofitting, replacing (reversible) air conditioners and direct electric heaters, respectively.

This situation is due to both economic and technical reasons. Existing hydronic heat distribution systems require high supply temperatures. They were traditionally designed for 80-90ºC supply temperature. However, heat pumps operating with HFC refrigerants have an operating temperature limit of 50-55ºC in most applications. This is not sufficient for monovalent operation in combination with a traditional hydronic distribution system. Another major drawback is that high distribution temperatures reduce the COP of the heat pump system, which results in a longer payback period. There are also physical constraints of a more basic nature, such as too little available installation space for a retrofit heat pump, and lack of suitable space for installing horizontal ground collectors.

Much can be done, technically, to improve the market prospects of heat pumps for retrofit. This is badly needed, as the Kyoto Protocol requires a significant reduction of fossil-fuel energy use. Heat pumps can reduce current global CO_2 emissions by 6%. This potential will be realised when 50% of residential and institutional/commercial buildings are heated with state-of-the-art heat pumps, which are capable of saving at least 30% CO_2 emissions compared to conventional heating methods. Heat pumps for retrofit can contribute significantly to achieving this, and the market for their application should therefore be stimulated.

Options for improving the chances for successful application of a heat pump in a retrofit project include:

1. Adapting the building and the design of the heating system;
2. Adapting the heat pump itself; and
3. Targeting specific applications.

Within the first group, a first option is to decrease the distribution temperature required. This can be done by improving insulation standards, removing night setbacks, or by (partly) retrofitting with a low-temperature heat distribution system. The last method is most expensive. Instead of decreasing the distribution temperature in a hydronic system, it is also possible to install ductless reversible heat pumps in the rooms to be conditioned.

Another solution of the first group is bivalent operation, which is quite common in many countries. The heat pump preheats the water, and the auxiliary heating system provides the temperature top-up. The capacity of the heat pump is only about 50% of the designed capacity of the system at maximum load, so the investment for the heat pump will be lower. More important, the sink temperature of the heat pump will be lower. However, the annual system efficiency must be high enough to ensure energy cost savings for payback of the heat pump system. This is especially a concern when electricity is used for auxiliary heating, as its costs per kilowatt-hour may be three to four times those of oil or gas. Despite this, bivalent operation is a common technical solution.

The second group of solutions includes modifications to the single-stage electric compression heat pump to produce higher supply temperatures. This can be achieved by choosing another refrigerant than the HFCs. Propane/butane mixtures and ammonia are examples of refrigerants that can perform well at about 70ºC. CO_2 is a promising candidate too, especially so because the temperature glide in the gas cooler of a CO_2 heat pump enables a large difference between supply and return temperatures, so high supply temperatures are favoured.

Technical changes can also be made to the conventional heat pump cycle to achieve a higher efficiency at high distribution temperatures. In Switzerland, several projects to develop and test such heat pumps were completed in 1999 and 2000. They include a heat pump with a separate loop for refrigerant condensate sub-cooling, a heat pump with intermediate vapour injection, a small two-stage heat pump and one with suction gas superheating and two-phase intermediate refrigerant injection. These options resulted in COP improvements ranging from 0-15%, and capacity improvements at high temperature lifts ranging from 5-30% compared to standard single-stage equipment.

Absorption heat pumps are specifically suitable for retrofitting conventional heating systems. A high-temperature generator, such as an oil- or gas-fired burner, is already integrated in the heat pump, and can be used for auxiliary heat production. The absorption heat pump needs a smaller heat source than an electric heat pump, which can be advantageous in a retrofit situation. Products designed for the residential market are currently under development in both the Netherlands and Austria.

The third group of potential solutions calls for a targeted choice of applications for retrofit with heat pumps. These are typically applications where long operating hours and steady loads guarantee cost savings and payback of the investment for the heat pump. Though these considerations apply to all heat pump systems, they are most important for heat pumps in retrofit applications. Examples are space and hot water heating in health institutions and old peoples' homes, and production of hot water in various situations, ranging from single-family houses to industry.

The expertise and knowledge needed for developing and installing heat pump systems for retrofit applications are available. Energy policy makers and utilities can benefit from supporting heat pumps for retrofit. They contribute substantially to reduction of CO_2 emissions and offer modern, comfortable and sustainable heating solutions.

Appendix

Appendix 1 Map of locations

This map shows cities mentioned in Figures 2.3, 3.1 and 3.5, and section 3.4.3.

Figure A1.1 *Cities mentioned in the report*

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Retrofitting with heat pumps in buildings

The market for heat pumps in new buildings has been expanding in some countries. Attention to the retrofit market is also increasing, in the wake of the market for new buildings. Several initiatives are being taken to remove market barriers to increased heat pump deployment in retrofit applications.

The market potential for heat pumps in existing buildings is substantially larger than for new buildings. Yet this potential is far from being realised in many countries, largely due to the high distribution temperatures required in existing heat distribution installations. To contribute to a worldwide reduction of CO_2 emissions, increased deployment of heat pumps for retrofitting is essential.

This report, a survey, provides insight into the residential heat pump market and the initiatives to promote heat pump use in retrofit situations. It contains useful information for architects and planners, as well as for policy-makers and utilities, who can play an important role in increasing the use of heat pumps.

ISBN 90-73741-41-6